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The Brackelsberg Furnace

As A Foundry Melting Unit

by Edwin F. Cone

SUPPLEMENTING THE ALREADY VARIED types of melting equipment for the foundry, there was introduced to American foundrymen at the A.F.A. meeting in 1932, in a paper by D. J. Reese entitled "Melting Iron in the Rotary Pulverized-fuel-fired Furnace," the Brackelsberg furnace, originating in Germany. Since then several installations of this furnace have been made in various American and Canadian foundries.

Acceptance here has been much slower than abroad, possibly on account of the limitations as to lining life, which increase as the operating temperature rises. Limitations as to the use of borings and light scrap in the oxidizing atmosphere may also have something to do with it. No data on metal losses in melting are available for publication. There are some 125 units of this type operating in Europe, it is said, on gray iron, malleable iron and steel. In the United States most of the installations are for gray or malleable iron with none on regular steel for castings. The nearest approach to steel is the production in these furnaces of the high-carbon copper-silicon ferrous alloys of the Ford type.

The Furnace Described

This furnace consists of a cylindrical steel shell with a refractory lining. It is open at both ends and rotates mechanically on its axis at about 1 r.p.m. It can be tilted both for charging and for slagging. The movements of the furnace are actuated by electric controllers and the control equipment is mounted on one board at an operating station. The cylindrical portion of the shell, one piece, is

Firing End of an 8-Ton Brackelsberg Furnace at the Plant of the Kelsey-Hayes Wheel Co., Detroit. Two more furnaces are in the background.

supplemented at each end by cone-like additions which are also refractory lined. The charging is usually accomplished from a charging platform, the furnace being tilted at an angle to receive the charges.

Powdered coal, used as the fuel, requires more combustion space than does gas or oil, so these furnaces have to be rather large for their melting capacity, as compared with an oil-fired furnace, for instance. Hence convenient sizes seem to run from 5 tons capacity up, rather than down, and the type of furnace seems more fitted to the larger rather than the smaller sizes.

Maintenance of a silica lining is of course, easiest when the lining is not allowed to get too cold, so continuous operation, or keeping some heat on the furnace when it is idle, is advisable from the point of view of refractory costs.

Some Advantages Claimed

It is claimed for this furnace that high quality castings can be made at low cost. For example, pulverized coal is the fuel and this is, of course, cheap in most foundry centers—cheaper on a B.t.u. basis than coke, oil, gas or electricity. The Whiting Corp., at Harvey, Ill., builders of this furnace, cite the fact that in coal producing areas, coal is generally 50 per cent of the price of coke. Assuming fuel ratios of 1 to 6 on low tonnage cupolas or daily melts comparable to a Brackelsberg furnace of 25 tons daily capacity, 1 to 3 on air furnaces of 25 tons capacity and 1 to 6 on Brackelsberg furnaces with suitable recuperation, in continuous operation, when everything is running well and there are no unusual delays, there is a possible saving in fuel cost with the Brackelsberg or some 50 per cent of that on the cupola and 50 per cent of that on the air furnace. Recuperation is essential, both for fuel economy and in order to secure high melting temperatures. About 900 deg. F. on the incoming air can be obtained without too much difficulty from recuperator life. Recuperation, however, is not attractive in small sizes.

Among other advantages claimed for this type of furnace there may be mentioned low labor cost, satisfactory or close metallurgical control, a temperature range suitable for cast and malleable iron, flexibility, and adaptability to duplexing.

The Cradle Furnace

Supplementing the Brackelsberg melting unit and advocated as an advantage where large scale melting operations are involved is a special type of refractory lined cradle furnace, fired also with pulverized coal. This provides a constant supply of metal and is arranged for lip pouring which eliminates expensive and troublesome taphole blocks and permits fast filling at pouring ladles. Fired with pulverized coal, its operating cost is low.

This being the general picture as to just what the Brackelsberg furnace is, the writer sought to obtain information from users as to their experience with these furnaces. The result is the following, based on visits to two large foundries where Brackelsberg furnaces are operating —the foundries of the Kelsey-Hayes Wheel Co., Detroit, and of the Ford Motor Co. of Canada, at Windsor, Canada —where complete cooperation was afforded.

Side Tapping from an 8-Ton Brackelsberg at Kelsey-Hayes Plant in Detroit. Metal temperature is reported at 2850 to 2900 deg. F.

A 10-Ton Cradle Furnace in the Kelsey-Hayes Detroit Plant. The furnace may be tilted 22 deg. for lip pouring. The large ladle at the right is used to transfer molten metal from Brackelsberg furnaces to the cradle unit, fired by a No. 15 Whiting pulverizer.

Operations at the Kelsey-Hayes Wheel Co. Plant

LARGE scale operations with a battery of five Brackelsberg units in association with a cradle furnace are conducted by the Kelsey-Hayes Wheel Co. at Detroit. At the very fine new foundry at the company's McGraw plant where every modern facility is afforded, there are five 8-ton Brackelsberg furnaces, at least four of which are in operation when large scale production is demanded. In this case a cradle furnace is not only convenient but necessary—in fact, mass production is hardly possible without it. It acts as a holding reservoir or mixer for a group of direct melting furnaces, supplying superheated metal to continuous molding units.

Supplementing the Brackelsberg and the cradle furnace, there is a gray iron melting unit consisting of two cupolas and there is one electric furnace of about 6-ton capacity. The electric furnace is used principally in duplexing copper-silicon steel alternating in this process with the pulverized coal-fired cradle furnace as a holding unit as maintenance or other requirements may dictate. The cupolas supply metal to molding units producing cast iron brake drums of several different types for the automotive industry. These also supply high carbon hot metal for mixing with Brackelsberg furnace metal in duplexing copper-silicon steel.

Brake Drums Principal Product

At the plant now being discussed the Brackelsberg furnaces are almost exclusively being employed in producing metal for pouring, on a large scale, the brake drums for Ford cars. These are delivered, after heat treatment, to the River Rouge plant in Detroit not far away. That the operations are on a large scale is demonstrated by the fact that 240 molds per hour are poured containing two brake drums or 480 castings per hour—under normal full operating conditions.

For handling this larger production, this new foundry, scarcely three years old, is equipped with every modern facility in molding machines, material handling equipment of several types for sand, molding, pouring and so on. It is truly a picture of up-to-date foundry mass production.

Other products are made such as brake drums for General Motors' cars which are gray iron cast around a pressed steel shell, as well as other motor car parts. The main product, however, is Ford copper-silicon steel brake drums.

Composition of the Brake Drums

The production of the steel for the Ford brake drums is not a simple matter. The metallurgy, or the evolution of this drum, was described in an article in METALS AND ALLOYS, Vol. 8, November, 1937, pp. 303-306. The present day composition of the metal for the drums is as follows:

	Per Cent
Carbon	1.55 to 1.70
Silicon	0.90 to 1.10
Copper	2.00 to 2.25
Manganese	0.70 to 0.90
Phosphorus	0.10 max.
Sulphur	0.08 max.

This product is melted and refined in Brackelsberg furnaces in which the metal is brought to specification and to temperature and then transferred to a cradle furnace before tapping for pouring. For an 8-ton heat in the rotating furnaces, a cycle of about 3 hrs. from charging to charging is necessary so that about 8 heats per furnace in 24 hrs. are

The Charging End of Electric Heat Treating Furnaces for Brake Drums at the Kelsey-Hayes Plant in Detroit. The furnaces are built by the Electric Furnace Co., Salem, Ohio.

possible. At this plant, when full normal operations are scheduled, an average of 270 tons of metal per day are handled. As much as 300 tons of copper-silicon steel have been poured in one 24-hr. day.

Raw Materials Used in the Charge

A typical charge for one of the Brackelsberg units for producing the high-carbon copper-silicon steel for brake drums is as follows:

	Lbs.
Return scrap (Cu-Si)	9,000
Pig Iron (3 to 3.25% Si)	1,600
Pig Iron (2.25% Mn)	700
Steel scrap, low-carbon	4,190
Copper, scrap	110

The following additions are made, largely for slag control:

	Lbs.
Sand	200
Limestone	25
Firebrick	20

This charge is brought to a fused condition while the furnace is stationary. Rotation is started 40 to 50 min. after firing.

When this complete charge is melted and refined, a preliminary test is taken and analyzed, usually in about 2 hrs. after charging. A typical analysis is as follows:

	Per Cent
Carbon	1.10 to 1.50
Silicon	0.50 to 0.70
Manganese	0.35 to 0.50

After preliminary analyses, the necessary additions of molten gray iron, ferromanganese, ferrosilicon and perhaps copper, to bring the metal to the specified analysis are made.

Before transfer to the holding or cradle furnace the temperature should be, and usually is, 2800 to 2850 deg. F. In case it is not, a transfer is made to the electric furnace for superheating. In the cradle furnace the metal is held at temperature and all pouring is done from this.

Refractory Linings

The Brackelsberg furnaces are first lined with fire-clay brick on which is superimposed a silica brick lining. This lining will last a varied number of heats depending on the care in lining, e.g. to make proper allowance for the expansion of the silica brick, and the metal being made, i.e., the temperature involved. In the case of the high-carbon copper-silicon steel, the average is around 150 to 175 heats. It is the general practice to have on hand a spare shell for use when the one in operation gives out unexpectedly. The lining of each shell consists of a permanent course of fire brick, 4½ in. or 6 in. against the shell, which is not touched in regular maintenance. The working lining is of

One of the 5-Ton Brackelsberg Furnaces at the Windsor, Ont., Plant of the Ford Motor Co. of Canada. The equipment for powdered coal is shown in the left background.

silica brick, an inner course, 6 in. or 9 in. in thickness. Operation of these furnaces is reported as quite satisfactory.

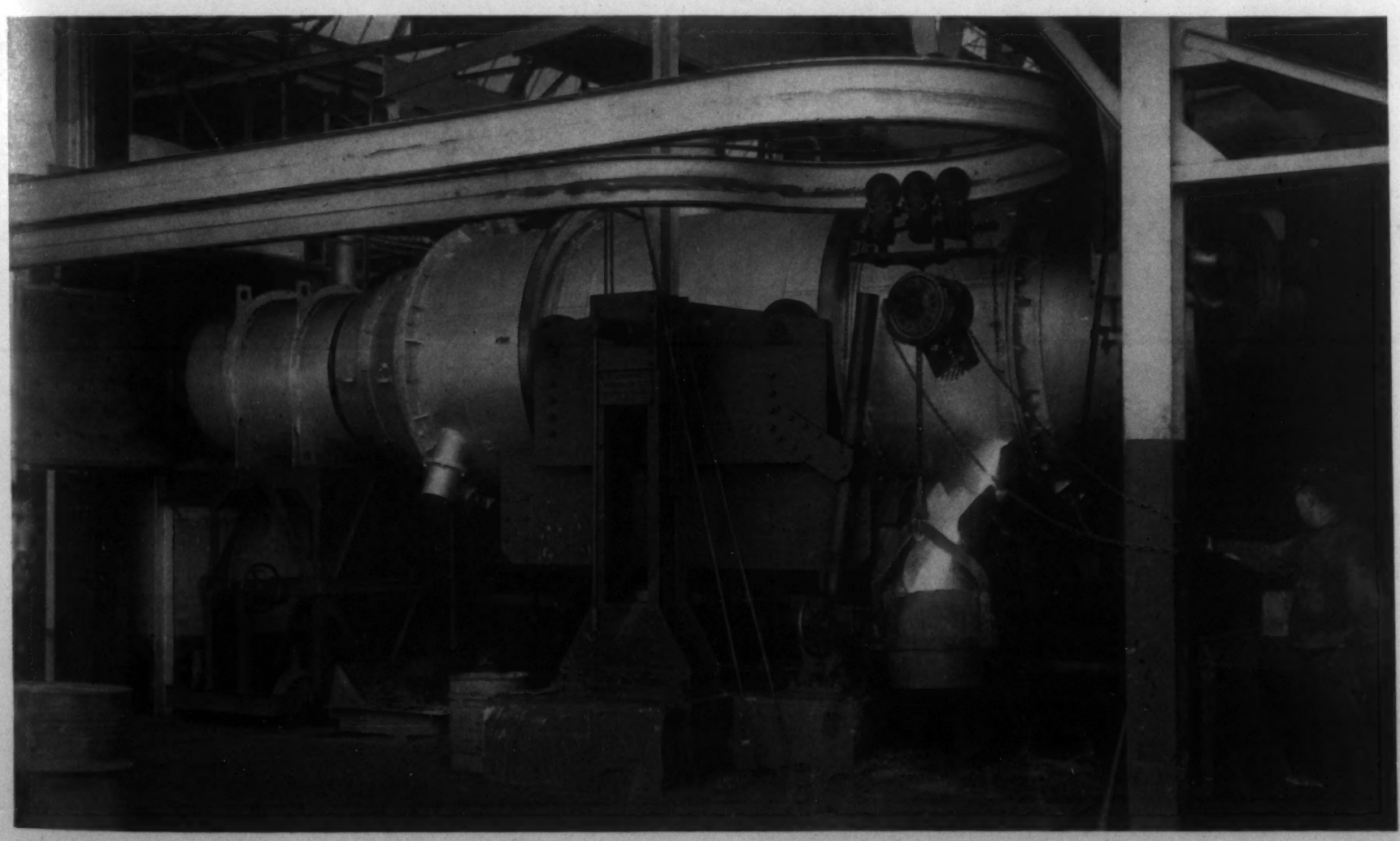
Experience of Ford Motor Co. of Canada

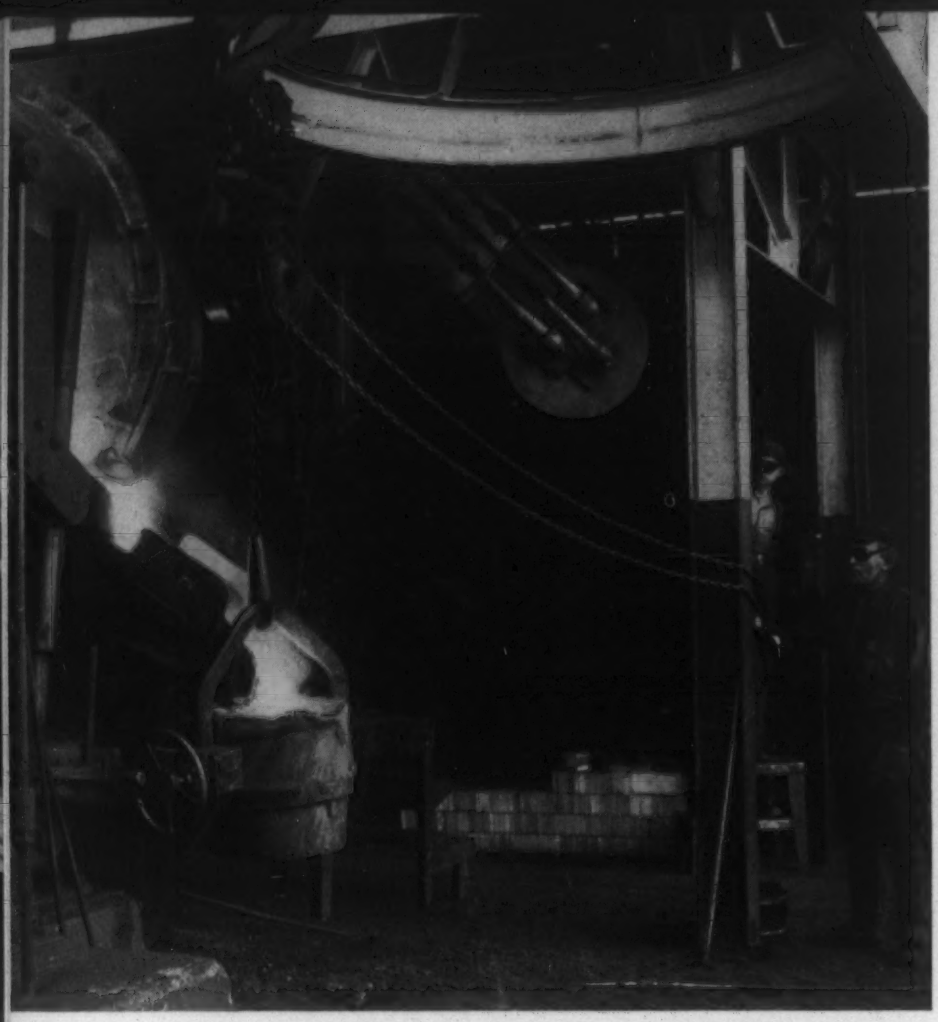
OPERATING solely on gray iron mixtures, the Brackelsberg installations at the plant of the Ford Motor Co. of Canada at Windsor, Canada, were reported as highly satisfactory. In this modern and up-to-date foundry, there are two 5-ton Brackelsberg furnaces as well as two Swindell and one Pittsburgh electric furnace. The electric installations are used largely for melting the high carbon copper-silicon steels which go into the crankshafts and the brake drums.

No Cradle Furnace Used

The two Brackelsberg furnaces in this plant are not supplemented by a cradle furnace as in some other installations. All pouring is directly from the furnaces. They

Pouring Cast Iron from a 5-Ton Brackelsberg Furnace at the Ford Plant in Canada.





Another View of Tapping from a 5-Ton Brackelsberg Furnace in Canada.

are fired with powdered coal and it is stated that, on the gray iron mixtures used, from 350 to 400 heats before repairing is not unusual. (This figure may be contrasted with that given above for the brake drum alloy, with its higher temperature requirement.) It may also be stated that, while in most cases tapping of the Brackelsberg from the firing end is regular practice, the Ford operators are successfully pouring from the opposite end—largely because this fits in better with the mechanical handling of ladles and molds. It had been contended by some that such practice would not be successful, particularly so far as clean metal is concerned.

Pouring Copper-Silicon Alloy for Crankshafts from a 9-ft. Diameter Swindell-Dressler Electric Furnace at the Canadian Ford Plant.

Clutch Plates and Fly Wheels Poured

The Brackelsbergs in this foundry are used only for making a gray iron for pouring clutch plates and fly wheels. These castings are poured in green sand, tapping direct from the Brackelsbergs with ladles traveling on overhead runways and pouring into molds on conveyors. These castings have no alloys—except sometimes a small percentage of copper in the fly wheels. No heat treatment is applied to these castings—they are used as cast.

Typical charges in the Brackelsbergs for these two types of castings are given as follows:

Fly Wheels

	Lbs.
No. 4 Iron 1.75% Si, 3.50% C, 1.60% Mn	2800
No. 2 Iron 3.00% Si, 3.50% C, 0.90% Mn, 0.45% P	400
Sprues	2000
Automobile scrap	4600
Machinery scrap	400
Bundled steel, low carbon	800
	10600
Copper	45
Ferromanganese	30
Carbon as electrode borings	250

Clutch Plates

No. 1 Iron 3.50% C, 3.00% Si, 0.90% Mn, 0.20% P.	1600
No. 2 Iron Same as for Fly Wheels	1000
Sprues	2000
Automobile scrap	2600
Forgings (0.35% C, 0.70% Mn)	100
Bundled steel, low carbon	900
No. 5 Silvery Iron (16 to 18% Si)	320
	8520
Carbon as electrode borings	250

It is stated that it is not unusual on these mixtures to make five heats in 8 hrs. Carbon to replace that lost in melting is obtained by the use of borings secured from old carbon electrodes. Thus the adding to the hot metal of gray iron from a cupola, practiced in some cases, is not found necessary at this plant. Temperatures up around 2700 to 2750 deg. F. for pouring these castings are not difficult to secure regularly. These units are lined first with fire-brick and then silica, the same practice as at the Kelsey-Hayes plant.

Cost, Fuel and Refractory and Other Data

Monthly cost data on the basis of tonnage were asked for from both users of the Brackelsberg furnaces but were unobtainable. From another source comes the statement that, at a plant such as the Kelsey-Hayes, such data are hard to get because so many furnaces—Brackelsberg, cradle and electric—all figure in the same total tonnage, and lately the cupola has entered the picture.

The same statement is claimed to hold true, regarding data on coal consumption on which no information was forthcoming.

As to refractory life, some difficulty was experienced in securing information. At the Ford plant in Canada, the statement was made that refractory life has been satisfactory with 240 heats per body lining.

As to metal losses, the only data obtainable from either user were to the effect that they were small at the Ford plant, but have not been exactly measured.

THE MANUFACTURE OF

Cast Trunnion Bearing Metal

AND ITS MECHANICAL PROPERTIES

Part I

by Joseph A. Duma

Assistant Metallurgist,
Norfolk Navy Yard,
Portsmouth, Va.

This paper describes: First, a foundry procedure for the melting of trunnion bearing metal; secondly, the effect of pouring temperature on its soundness and physical properties; thirdly, the influence of various elements, particularly aluminum and zinc, on the same; and finally, its heat treatability.

CAST TRUNNION BEARING METAL is finding an increasing acceptance in various applications where a low rate of wear, combined with a high resistance to steady or suddenly applied compressive loads, plus a low coefficient of friction between rotating and sliding surfaces, are required. Outstanding applications of this metal in cast form are in the field of ordnance, namely—trunnion bearings of turret mounts, bushings on carriages of ammunition hoists, miscellaneous bushings sustaining heavy loads and working under conditions similar to those encountered with trunnion bearings, certain types of worm gear, worm wheels, etc.

The brass which most closely resembles trunnion bearing metal, structurally and compositionally, is manganese bronze. Navy Ordnance Specifications No. 550, dated Dec. 1931, for Trunnion Bearing Metal (Cast), state that this alloy shall have the following minimum physical values and chemical composition.

Physical Values (Minimum):

T.S.	Y.P.*	Elongation,	Reduction,	Brinell,
100,000 psi	55,000 psi	15% in 2"	15%	200

Chemical Composition:

	Per Cent Desired	Per Cent Permissible Range
Manganese	4.25	3.50 to 4.50
Nickel	None	.....
Tin	None	0.02 maximum
Lead	None	0.02 maximum
Iron	2.50	2.00 to 3.00
Aluminum	5.25	4.50 to 6.00
Copper	Remainder	Remainder
Zinc	20.50	19.00 to 22.00
Total impurities	.....	0.50

* Stress at which the elongation of the bar reaches 0.01 in. on a 2-in. gage length.

In order to meet the exacting requirements of this specification, it is apparent that not only must each component metal be of the highest quality obtainable but that the utmost of care be exercised in its weighing, its melting, and in the final deoxidation and pouring of the resulting alloy. The composition and the temperature for melting and pouring trunnion bearing metal are so critical that the slightest physical or chemical diviation from normal practice will result in impaired physical properties.

FOUNDRY PROCEDURE FOR MELTING

THE procedure used in the manufacture of three crucible heats of trunnion bearing metal—one of 200 lbs., one of 300 lbs., and the other of 350 lbs. burden—will be described. All three of these heats were made expressly for a study of the effect of pouring temperature on mechanical properties. The quality of the virgin metals employed were as follows:

Metal	Commercial Designation
Copper	Grade A ingot (prime electrolytic)
Zinc	Slab (spelter), Grade A
Aluminum	Primary aluminum, Grade A ingot
Manganese	Ferromanganese, lumps, 80 per cent
Iron	Wire nails, low carbon
Mn-Cu	30% manganese, deoxidizer
P-Cu	15% phosphorus, deoxidizer

Order of Charging

The above materials were charged in the following order into clay-lined, No. 80 and No. 150, Lava crucibles preheated in coke-fired crucible furnaces.

(1) Copper:
  a) All but one or two pigs, depending upon the size of the heat, were melted down under salt (6 oz./100 lbs. of charge), without pot cover.
  b) The melt was heated to 2350 deg. F.

(2) Iron:
Iron nails were warmed on top of bath and were then submerged and incorporated into the bath with vigorous stirring. From 45 to 60 min. were required for the complete melting of the iron.

(3) Manganese:
Ferromanganese, approximately 3 lbs. at a time, was added and stirred into the bath. About 20 min. was allowed for its dissolution.

(4) Aluminum:
a) Aluminum was introduced into the bath next, with stirring. Melting was almost instantaneous.
b) The temperature of the bath was lowered to 1900 to 2000 deg. F. with an addition of the remaining copper.

(5) Zinc:
After an interval of 10-15 min., zinc was alloyed with the bath.

(6) Mn-Cu:
a) Another 15 min. was permitted to elapse before the final addition, i.e., manganese-copper (generally 2½ oz. per 100 lbs.).
b) The crucible was pulled and the metal pigged. The time consumed in preparing the trunnion bearing metal ingot varied from 3 to 3½ hrs.
c) Remelted the ingoted metal, under salt with rapid heating. The metal in crucible 333 was heated to 2250 deg. F., that in crucible 334 to 2150 deg. F., and crucible 362 was heated to 1950 deg. F.

(7) Aluminum and Zinc:
To crucible 362, 2 per cent zinc and ½ per cent aluminum were added, the aluminum first and then the zinc. No additions of these metals were made to either crucible 333 or 334.

(8) P-Cu.:
a) The crucibles were held at their respective temperatures for approximately 15-20 min. They were then deoxidized with P-Cu (1 oz. per 100 lbs. of metal).
b) The pots were then pulled and test bars were poured at the following temperatures, the time consumed in remelting being approximately 1½ hrs.

Heat No. 333	Heat No. 334	Heat No. 362
Block A = 2250 deg. F.	A = 2100 deg. F.	A = 1850 deg. F.
Block C = 2100 deg. F.	C = 1900 deg. F.	
Block E = 1900 deg. F.		

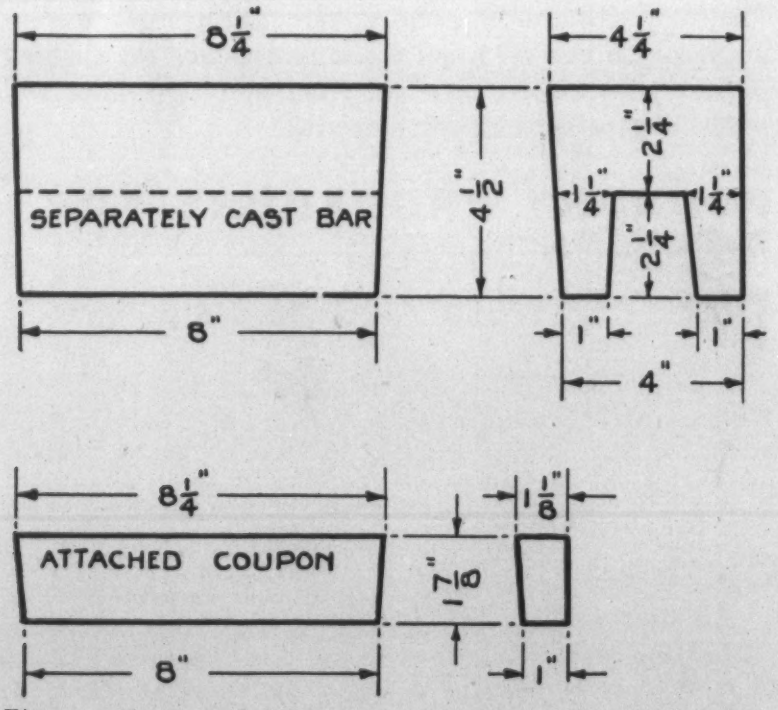


Fig. 1.—Form and Dimensions of "Block" Type Test Bars

The above procedure for melting is not entirely inflexible, but can be varied in many places, and this with almost imperceptible effect on physical properties. For example, additions Nos. 3 and 4 can be interchanged without any detectable effect on the resulting mechanical properties.

Additions Nos. 5 and 6 have likewise been tried transposed, but without any observable advantageous or disadvantageous effects. It is a well-known fact that when aluminum is added to liquid copper, there is an appreciable and immediate rise in temperature[1], due in part, to the heat of formation of the resultant alloy and in part to the thermit reaction between aluminum and oxygen. For this reason, aluminum is oftentimes added before any final copper addition. The primary object of the copper addition at this stage of melting is to reduce the temperature of the bath from approximately 2350 to 2000 deg. F. in order to insure low volatilization losses for the zinc additions immediately following. In tests, however, it was found that aluminum caused very little change in temperature. It, therefore, was introduced after the copper.

In connection with the remelting of pigged metal, the fundamental principle of rapid melting and prompt pouring was observed. Due regard for this principle prevents excessive oxidation losses.

Table I—Effect of Pouring Temperature on Tensile Properties

Heat No.	Pouring Temp., deg. F.	Activity of Metal	Tensile Strength,* lbs. per sq. in.	Yield Point,† lbs. per sq. in.	Elong., per cent in 2 in.	Red. Area, per cent	Appearance of Fracture
333A	2250	Very wild	57,000	30,000	15.0	22.19	Gassy
333C	2100	Wild	72,250	31,000	44.0	45.63	Clean
333E	1900	Quiet	73,250	31,250	44.5	43.50	Clean
334A	2100	Wild	82,500	42,500	17.0	18.83	2 dirt spots
334C	1900	Quiet	85,750	46,000	21.5	22.35	Clean
119	2000	Quiet	100,750	58,000	10.5	15.50	Clean
397‡	1850	Quiet	101,500	60,000	18.0	20.60	Clean
362	1850	Quiet	115,500	82,250	17.	19.89	Clean

* The values shown are the average of 2 specimens.
† Stress at which the elongation of the bar reaches 0.01 in. in a 2-in. gage length.
‡ 397 is 119 remelted.

EFFECT OF POURING TEMPERATURE

THE temperature of the melt before pulling the crucibles was determined with an "Alnor" pyro-lance. When the melt temperature was high enough to insure a sufficiently high initial casting temperature, the crucibles were pulled and the final reading was checked with an extensible bare wire 14 gage chrome-alumel couple used in conjunction with a portable potentiometer.

Type of Test Bar

All the trunnion bearing metal heats used in this investigation were poured into "block" type test bars having the

Table II—Effect of Melting Temperature on Chemical Composition

	Heat 333		Heat 334		Heat 362 *	
Melted at	2250 deg. F.		2100 deg. F.		1875 deg. F.	
Weight, BM	300 lbs.		200 lbs.		358.8 lbs.	
Weight, AM	272.5 lbs.		185.1 lbs.		351.5 lbs.	
Loss	27.5 lbs.		14.9 lbs.		7.3 lbs.	
Loss	9.16%		7.40%		2.10%	
	Original Per Cent	Final Per Cent	Original Per Cent	Final Per Cent	Original Per Cent	Final Per Cent
Copper	66.55	73.31	66.08	71.37	66.08	65.78
Zinc	20.96	16.75	22.11	18.58	22.11	23.32
Aluminum	5.45	3.14	5.40	4.53	5.40	4.80
Manganese	4.21	3.75	3.88	3.51	3.88	3.61
Iron	2.83	3.05	2.53	2.01	2.53	2.49
	Melting Loss, Per Cent of Charge		Melting Loss, Per Cent of Charge		Melting Loss, Per Cent of Charge	
Copper	None		None		None	
Zinc	5.75		4.95		0.67	
Aluminum	2.56		1.20		1.18	
Manganese	0.83		0.55		0.23	
Iron	0.02		0.70		0.02	
	9.16		7.40		2.10	

BM = Before Melting.
AM = After Melting.
* = 7 lbs. zinc and 1.75 lbs. aluminum were added to 362 on remelting.

Table III—Combined Effect of Aluminum and Zinc on Tensile Properties

Heat No.	Premelting Composition, Per Cent					Remelt Additions, Per Cent		
	Cu	Zn	Fe	Mn	Al	Al	Zn	
334*	66.08	22.11	2.53	3.88	5.40	1.00	2.00	
362	"	"	"	"	"	0.50	2.00	
370	"	"	"	"	"	0.50	2.00	
379	"	"	"	"	"	0.50	2.00	
380	"	"	"	"	"	0.75	1.50	
397	"	"	"	"	"	0.25	2.50	
400	"	"	"	"	"	0.25	1.50	
398	"	"	"	"	"	0.50	1.00	
401	"	"	"	"	"	0.50	2.00	0.50 Ni

	Physical Properties			
	Tensile Strength, lbs. per sq. in.	Yield Point, lbs. per sq. in.	Elongation, Per Cent	Red. Area, Per Cent
334	94,500	55,000	15.5	20.00
362	115,500	82,250	17.0	19.89
370	112,000	83,500	14.0	17.39
379	113,750	81,750	14.0	17.03
380	115,750	84,750	13.0	15.58
397	101,500	60,000	18.0	20.60
400	101,500	59,000	16.0	20.60
398	104,750	64,500	15.0	17.75
401	106,750	77,500	11.5	15.58

* Remelted for the 3rd time.

dimensions shown in Fig. 1, and the tensile test specimens machined therefrom were of the standard cylindrical type, with a 2-in. gage length and 0.505-in. diameter. Blocks were cast in green brass sand molds without artificial chilling. The sand had the following average physical values: Grain fineness, 175; A.F.A. permeability, 13-17; moisture, 8 per cent; clay content, 12 per cent.

Physical Properties and Composition

Temperature exerts its effects on final physical properties by altering the initial casting composition of the metal. High temperatures accelerate chemical reactions, particularly the rate of oxidation and the speed of volatilization. The degree of damage done to physical properties by high temperatures is shown in Table I and Fig. 2. Three important facts are contained in the graph of Fig. 2, namely:

(1) The temperature range, 2100 to 2350 deg. F., is most damaging to the physical properties of trunnion bearing metal, causing an immediate and rapid fall of strength with rise in temperature. This is not surprising when it is remembered that the range is some 485 to 685 deg. F. above the boiling point of zinc (1665° F.[2]).

(2) The tensile strength of trunnion bearing metal is increased as the temperature to which it is heated in remelting is decreased (represented by the broken line in the diagram).

(3) And, all other things being equal, tensile strength improves materially when the pouring temperature is lowered (represented by the gradual slope of lines 333, 334, and 119 to 379). It appears, therefore, that the best range of temperature for remelting is 1900 to 2000 deg. F., and that the best pouring temperature is 1850 to 1875 deg. F.

Chemical analysis of drillings taken from the grip end of tensile bars disclosed the basic reason for these changes. In Table II are shown the analyses of heats 333, 334, and 362, both before and after melting. The figures, as they stand, shed very little light on melting losses, since melting losses cannot be determined unless the final weight is known. The losses stated in Table II were calculated on the assumption that the heaviest oxidation losses should be suffered first by aluminum, then manganese, and finally zinc. Iron and copper, particularly copper, should scarcely oxidize at all. The final weight of the melts shown in Table II was calculated on the assumption that the copper losses were negligible.

Table IV—Various Compositions Which Have Met Specification Requirements

Heat No.	Final Chemical Analysis, Per Cent					Tensile Strength, lbs. per sq. in.	Elong., per cent
	Cu	Zn	Fe	Mn	Al		
361	67.50	20.75	2.42	3.91	5.42	110,000	16.0
362	65.78	23.32	2.49	3.61	4.80	115,500	17.5
367	64.28	[illegible]	2.47	3.78	5.67	119,000	15.5
397	68.51	[illegible]	2.10	3.34	4.50	101,500	18.0
440	67.48	22.26	2.27	2.64	5.34	104,500	15.0
454	66.58	21.86	2.49	3.61	5.43	100,500	15.0

RELATIONSHIP OF COMPOSITION TO PHYSICAL PROPERTIES

THE comparatively poor physical properties of heats 333 and 334 are directly traceable to a change in composition occasioned by high melting losses of zinc and aluminum. Under normal conditions of melting the average zinc and aluminum losses rarely exceed 3.00 and 1.00 per cent respectively. When one-half of each of the above losses is repaired by replacement during the remelting of the ingoted metal, the physical properties soar up to values well in excess of the specification requirements.

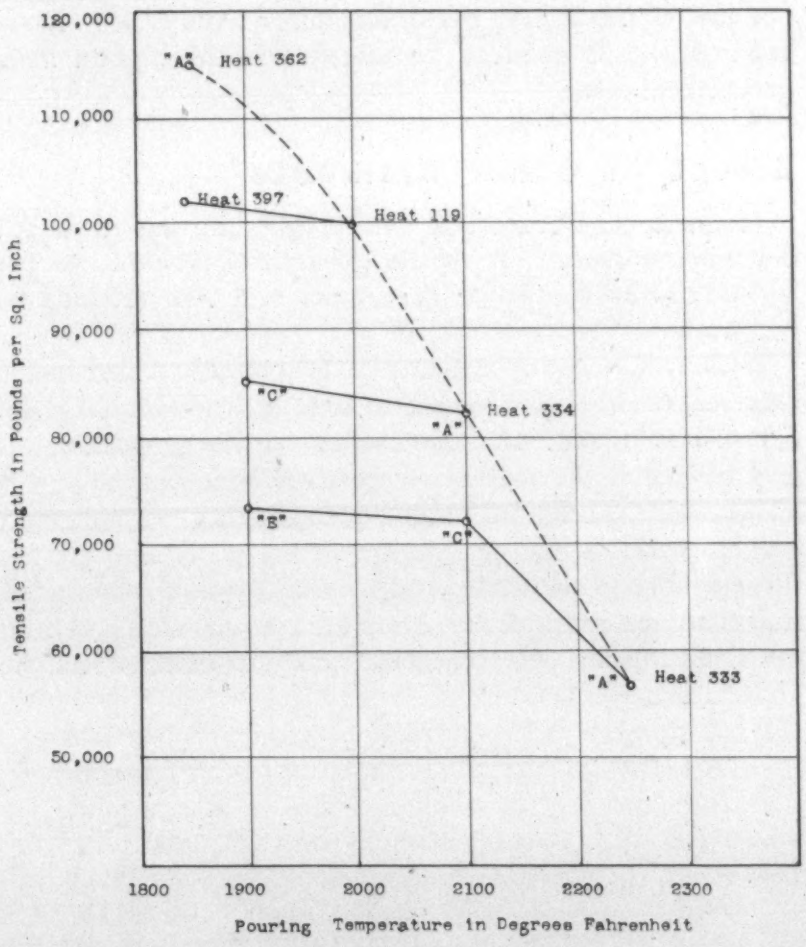


Fig. 2.—Showing Relation Between Pouring Temperature and Tensile Strength

The data in Table IV show how physical properties change when these extra additions of zinc and aluminum are made to the remelted metal. The heats were melted according to the outline previously given; they were heated to approximately 1950 to 1975 deg. F. and poured at 1850 deg. F. From the evidence presented in Table III it is concluded that, if the initial premelting mixture is of the proper composition, the addition thereto of 1.50 to 2.00 per cent zinc (preferably 1.80%) with 0.25 to 0.50 per cent of aluminum (preferably 0.35%) will give a metal possessing excellent tensile properties.

Effect of Manganese

All things being equal, manganese and aluminum are interchangeable within a certain range of composition. It appears that 1 per cent manganese is equivalent to 1 per cent aluminum in its effect on tensile properties. We hasten to add, however, that manganese in amounts exceeding 4.00 per cent is deleterious to cold ductility. The following heats are offered in support of the above claims:

Heat No.	Final Chemical Composition Cu	Zn	Fe	Mn	Al	Tensile strength, lbs. per sq. in.	Yield point, lbs. per sq. in.	Elongation, per cent	Red. area, per cent
397	68.51	21.55	2.10	3.34	4.50	101,500	60,000	18.0	20.50
440	67.48	22.26	2.27	2.64	5.34	104,500	63,000	15.0	17.00
308	66.25	22.00	2.31	4.60	4.81	109,250	74,500	10.0	14.00
362	65.78	23.32	2.49	3.61	4.80	115,500	82,250	17.5	19.89
367	64.28	23.81	2.47	3.78	5.67	119,000	82,250	15.5	18.00
A6-1A	69.75	17.57	2.58	5.10	4.71	106,500	64,500	11.5	13.00

Heats 397 and 440 vary with respect to manganese and aluminum, the low manganese in 440 being offset by the high aluminum. Heats 308 and 362 have approximately the same aluminum content but different manganese content, and heats 362 and 367 have approximately the same per cent of manganese but different per cents of aluminum. Heat A6-1A is included because it was the highest manganese heat made.

Effect of Other Elements

Magnesium: Deoxidation with magnesium was attempted but without success. A tensile strength of 50,000 lbs. per sq. in. and an elongation of 0.5 per cent was obtained on one heat.

Nickel: The incorporation of 0.50 per cent nickel in the form of 70:30 copper-nickel to heat 401 (Table III) did not result in any improvement of tensile properties. It may be that higher additions are more beneficial.

Titanium: Trunnion bearing metal ingots, without zinc, can be made in the electric arc furnace. A few electric furnace heats were made, and to each a small quantity of ferrotitanium was added. After the zinc addition had been made in the crucible, chemical analysis detected in the metal 0.02 to 0.06 per cent titanium. All these heats gave a tensile strength in excess of 100,000 lbs. per sq. in. with elongation values ranging from 4.0 to 10.0 per cent. One of the best heats was the following:

Heat	Cu	Zn	Fe	Mn	Al	Ti	T.S.	Y.P.	Elon.	R.A.
325	66.93	23.11	1.92	4.29	3.51	0.04	120,000	78,750	10.0%	13.38%

Silicon: Crucible trunnion bearing metal contains residual silicon in amounts ranging from 0.06 to 0.12 per cent. The effect of this silicon, in the presence of so many other variables, is difficult of determination. Electric furnace heats were found to contain from 0.20 to 0.40 per cent silicon. Its effects were also masked by other variables. Higher silicon tends toward embrittlement. A heat in point is the following:

Heat No.	Cu	Zn	Fe	Mn	Al	Si
155	67.38	23.78	1.26	1.35	5.62	0.61

which when tested gave a tensile strength of 72,000 lbs. per sq. in. and an elongation of 1.0 per cent.

Range of Analysis

Table IV lists all the chemically analyzed heats which have met specification requirements. Looking them over, it appears that good trunnion bearing metal can be expected when its analysis falls within the following percentage range of composition:

Copper	Zinc	Iron	Manganese	Aluminum
64.25 to 68.50	20.75 to 23.35	2.10 to 2.50	2.65 to 3.80	4.50 to 5.70

It will be noted that this calls for a lower manganese content and higher zinc content than the "desired" values of the specification, making a reasonable desired composition of about 3.0 Mn, 5.0 Al, 2.3 Fe, 22.0 per cent Zn, balance Cu.

(To be concluded)

References

[1] Anderson, R. J. "Metals of Aluminum and Aluminum Alloys," p 162. Henry Carey Baird & Co., New York.
[2] International Critical Tables, Vol. 1, p. 103.

FACTORS AFFECTING THE

Life of Cast Iron Ingot Molds

——AN EXTENDED ABSTRACT

by Fred P. Peters

Assistant Editor, METALS AND ALLOYS.

This is the concluding installment of an extended abstract of the Iron and Steel Institute's Seventh Report on the Heterogeneity of Steel Ingots, the first part of which, covering internal evidences of heterogeneity, was published in the April issue.

SINCE 1934 A JOINT SUBCOMMITTEE of the Heterogeneity of Steel Ingots and the Open-Hearth Committees of the Iron and Steel Institute has been following a program designed "to examine all factors, including mold design, composition, mode of manufacture and utilization, governing the life of ingot molds, and their effect on steel quality." To date, attention has been concentrated on the factors affecting mold life, consideration of steel quality having been postponed until later. In this, its first report,[5] the Subcommittee offers (1) an enumeration of 22 manufacturing and service factors (with their subdivisions) capable of affecting the life of ingot molds; (2) a determination, through practical works experiments and statistical evaluation of individual production records, of the relative importance of these factors; (3) a correlation of extensive tabular data on ingot mold manufacture and use; (4) a paper by J. G. Pearce on composition and structure as affecting mold failures; and (5) a bibliography containing brief abstracts of the literature on ingot molds from 1899 to January, 1937.

Practical Works Experiments

Careful tests on the effect of different mold raw materials on mold life showed that the relative proportion of hematite iron, mold scrap and steel scrap in the mixture was of no importance. There was a slight average increase (2%) in mold life due to the addition of 0.3 per cent chromium, but this is more than offset by the increased cost of such a mixture. A phosphorus content of 0.17 per cent gave an 8 per cent greater mold life than one of 0.075 per cent. Molds made of hematite iron (2.41 T.C., 2.28 Si, 0.032 S, 0.032 P, 0.85% Mn) partly blown in the converter cracked the first time they were used.

Reduction of the time interval between teeming and stripping brings a pronounced improvement in mold life. Thus, 21 molds stripped 13 min. quicker than the shop average of 60 min. showed a 9.2 per cent average increase in mold life; another group, stripped 40 min. as compared to the customary 90 min., benefited to the extent of 21 per cent; the average life of a third group was increased 38.4 per cent by stripping in 45 min. instead of 90 min. Doubling the customary time interval, however, brought no decrease in mold life, indicating that the time interval must be short enough to prevent the mold reaching its maximum temperature if any benefit is to be derived from earlier stripping. In none of these tests was any deleterious effect on steel quality observed by decreasing the time before stripping. This does not mean, however, that early stripping may not be harmful to the quality of other steels.

The relative effect of the carbon content of the steel ingots on the life of the mold was examined. Molds used with steels containing less than 0.25 per cent C lasted 13 per cent longer than those used with steels of more than 0.40 per cent C.

Individual Production Records

The mold service records available to the committee yielded some very interesting information. Manganese content of mold iron was very important. As the Mn content increases, the molds tend to fail by surface disintegration (crazing) rather than by cracking. Increase of Mn content from 0.75 to 1.0 per cent increased mold life 14 per cent. With Mn constant, increase in Si content also increases the tendency of the molds to fail by crazing, rather than cracking. Increase in Si, however, decreases mold life; an increase of Si content from 1.7 to 2.0 per cent reduced the average life of the molds 10 per cent.

Courtesy: J. T. Ryerson & Son, Inc.

An Impressive Array of Ingot Molds Receiving Open-Hearth Steel

Records of a large number of molds at two plants show definitely that no increase in mold life results from the aging of molds prior to use. Molds placed in service less than 1 week after manufacture had consistently as long life as those allowed to stand unused for periods up to 8 weeks.

The use of abnormally high steel casting temperatures, usually an isolated accidental occurrence, may ruin new or used molds. With respect to the temperature of the mold just before pouring the steel, records showed that molds used in summer had shorter lives than those used in winter, and that the longer the time between successive casts (or the more effective the method of cooling the molds), the greater is the mold life.

In one plant mold life has been gradually increased about 100 per cent by modifying casting practice in certain respects over a period of 2½ yrs. The improvements included (1) the installation of air-cooling gantries to expedite cooling of the molds, (2) increase in Mn content of the molds from 0.7 to over 0.9 per cent, (3) pit bottoms

have been modified to permit greater air circulation around the molds, and (4) "swollen walls" were introduced to strengthen the mold and effect more rapid dissipation of heat from that part of the mold most prone to failure. The effects of these changes have been cumulative and cannot be individually evaluated.

Collective Experience

A questionnaire concerning existing practice in the manufacture and use of ingot molds was sent to a number of steel makers and the information contained in the answers has been correlated in several long, detailed tables and design charts included in the report. The data are as yet insufficient to permit easy isolation of the effect of individual factors, but several broad deductions can reasonably be made.

The life of big-end-up molds was, on the average, only 65 per cent of that of big-end-down; this difference is ascribed to the prevalent practice of inverting and bumping the big-end-up ingots for stripping, which subjects them to more abuse and handling than the big-end-down. Big-end-down molds show a life increase of 34 per cent for uphill teeming as compared to direct. No correlation was possible for big-end-up designs.

This statistical evaluation confirmed the previous experiments on a production scale that showed mold life to be a function of the time between casting and stripping. It is believed that, if more data were available, a characteristic curve relating mold life to casting-to-stripping time interval for each type and size of mold could be drawn.

The effect of wall thickness, or more specifically the ratio of wall thickness to ingot weight, is very interesting. The heavier molds with the lowest ratios fail largely by cracking, while the lighter molds with greater ratios fail by crazing. In fact, as the ratio increases the causes of failure change from almost 100 per cent by cracking to 100 per cent by crazing.

Russell,[8] in discussion, advocated the use of the conventional "mold ratio" (ratio of wall thickness to cross sectional area) in place of the ratio of wall thickness to ingot weight mentioned above as having some relation to the type of failure. Russell also said that all the statements made in the report about time between casting and stripping, the use of hot mold casting, the importance of wall thickness, the difference in average life in summer and winter, etc. could be summarized in the simple statement that the life of an ingot mold depended on the temperatures attained in use. True though this may be, it entirely ignores the superimposed effect of mold composition and manufacturing factors on life.

Optimum Composition and Structure

The influence of composition and structure on the failure of steel ingot molds is discussed in a paper by Pearce.[6] The paper is confined to failures due to cracking and crazing. To withstand major cracking an ingot mold must be able to resist thermal shock stresses caused by the impact of molten steel; to withstand minor cracking or crazing, the mold should be resistant to scaling and "growth." Because these two conditions are fundamentally opposed, the best solution in any case is a compromise.

Experience has proved that hematite gray iron, originally chosen for economic reasons, is a generally satisfactory material for molds. Small percentages of P (less than 0.3%) are beneficial. The higher the total C, the greater is the tendency to growth, but as the C content is lowered, the graphite becomes less coarse, casting shrinkage and internal stresses, and therefore the liability to thermal shock, increase. Increased Si, within the mold composition range, increases the tendency to growth by coarsening the graphite, and also hardens and embrittles the ferrite matrix, thus decreasing thermal shock resistance. Si content should be limited to the minimum required to make the iron gray, depending on the C content. Some latitude in C and Si contents is permissible because an increase in one can be offset by a suitable decrease in percentage of the other. Nickel is a graphitizer about 1/3 as strong as Si, but, unlike the latter, it toughens the matrix. Used in proper balance with the Si, Ni can reduce the tendency to growth and increase thermal shock resistance. Cr, as it is a strong carbide stabilizer, should be used only in small amounts to offset the effect of excessive Si.

The relative effects of these and other constituents of gray iron for molds in promoting graphite formation or in stabilizing carbide may be conveniently tabulated as follows:

Constituent	Graphitizing Value	Carbide-forming Value
Silicon	1	—
Manganese	—	0.25
Nickel	0.3-0.4	—
Copper	0.35	—
Molybdenum	—	0.35
Chromium	—	1.2
Aluminum	0.5	—

From the standpoint of structure, the most desirable feature is that the matrix be such as to provide high damping capacity. According to Pearce, irons with the largest graphite cavities possess the greatest damping capacity and therefore a large graphite percentage is important in ingot molds. Structurally, it is preferable to have a large number of small cavities than a small number of large; some cavities must be present, for although an ingot mold must be structurally rigid, it must also be capable of absorbing thermal stress and resisting thermal breakdown.

The most suitable compromise is probably an iron of such C and Si contents as to yield an all-pearlitic matrix, with flake graphite, and of the following composition:

Total Carbon—High—not lower than (4.3 — 0.3 x Si%)
Silicon—Such as to yield a completely gray, pearlitic iron
Sulphur—Below 0.1 per cent
Manganese—1.7 x %S + 0.3% minimum
Phosphorus—Below 0.1 per cent

Pearce suggests the application to ingot mold manufacture of Norbury and Morgan's method[7] of controlling graphite size. Using their process, it is possible to obtain extremely fine graphite structure in irons of the highest possible C content, a combination that is ideal for ingot molds. The method consists essentially in the addition of 0.1 to 0.2 per cent Ti to the melt and then bubbling carbon dioxide through it.

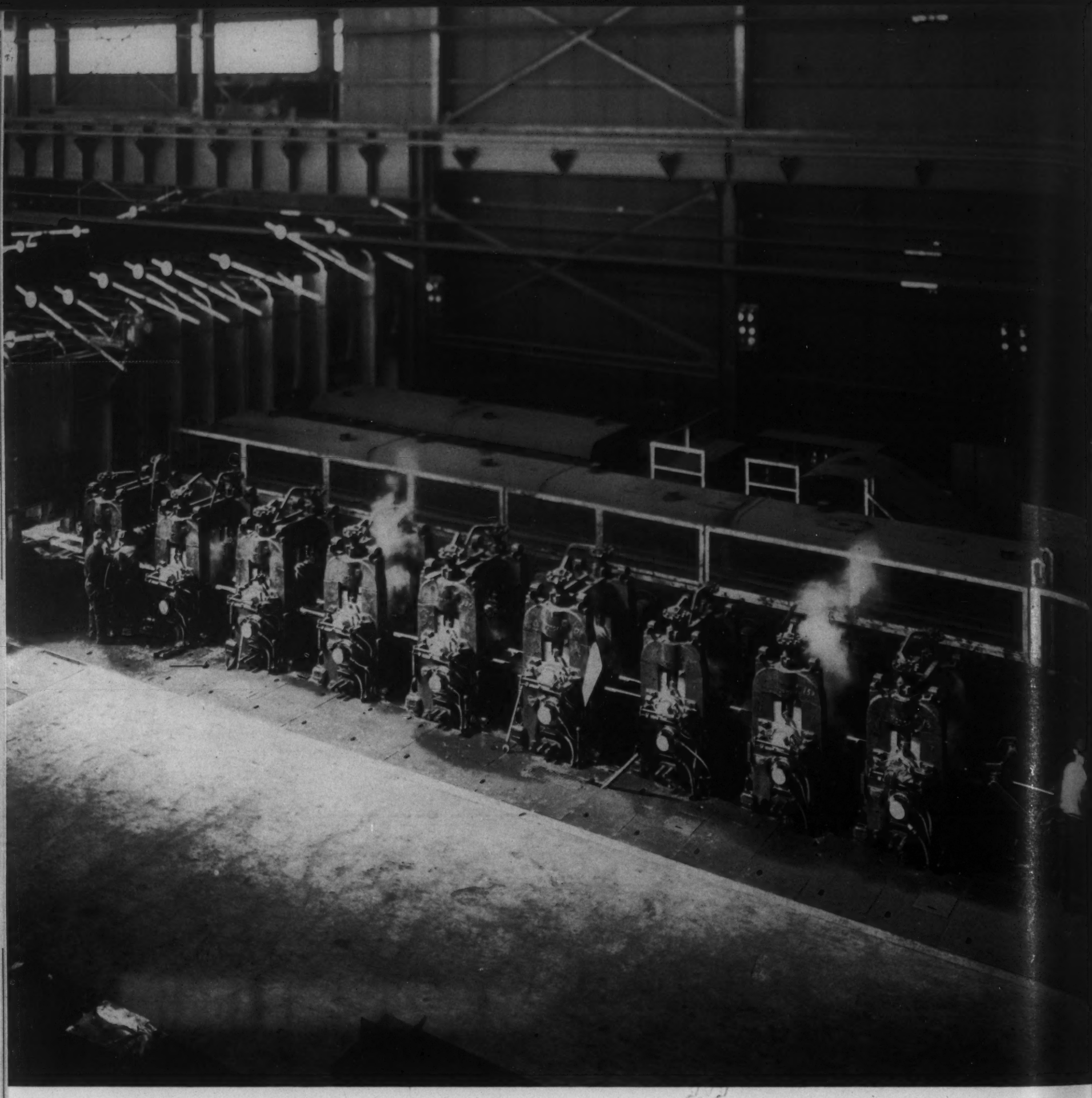
References

[5] "The First Report of the Ingot Moulds Sub-Committee." *Seventh Report on the Heterogeneity of Steel Ingots, Iron and Steel Inst., London* (Special Report No. 16) 1937, pages 143-213.

[6] J. G. Pearce. "The Failure of Ingot Moulds for Steel Ingots. The Influence of Composition and Structure." *Ibid.*, pages 185-195.

[7] A. L. Norbury and E. Morgan. "The Effect of Non-metallic Inclusions on the Graphite Size of Grey Cast Iron." *J. Iron & Steel Inst.*, Vol. 134, No. II, 1936, pages 327 P-358 P.

[8] Russell. *J. Iron & Steel Inst.*, Vol. 135, No. I, 1937, page 370.



Courtesy: Bethlehem Steel Co.

Heating Furnace and Nine Roughing Stands in New Continuous Rod Mill at Maryland Plant

INFLUENCE OF OXYGEN ON THE

Aging of Iron and Steel

Part I

by A. B. Wilder

Assistant Professor of Metallurgical Engineering, University of Illinois, Urbana, Ill.

Abstract: *Iron of high purity was saturated with oxygen at 2372 deg. F. (1300 deg. C.) and lower temperatures. Quench and strain age hardening of the various alloys were studied. Low, medium and high carbon steels, after suitable heat treatment, were examined for strain and quench age hardening. Alloys of iron and oxygen exhibited marked strain aging but did not show quench aging to the degree expected. Armco iron and various low carbon steels behaved in the usual manner showing marked strain and quench aging. The medium and high carbon steels did not age harden after suitable heat treatment. The results of this investigation indicate that oxygen plays an important part in the age hardening of steel, especially after cold working. It does not appear that carbon is the only factor responsible for quench age hardening.*

THE BEHAVIOR OF OXYGEN in liquid iron has received the attention of metallurgists for many years. Comprehensive scientific information is available for those interested in the influence of oxygen in steel making. The unknown influence of oxygen in solid iron or steel represents an important field which has also received the attention of many metallurgists with less fruitful results. The quantitative determination of oxygen and the influence of small amounts of impurities have been the chief factors causing oxygen to have an unknown influence in solid iron.

Great improvements have been made in the determination of oxygen but to distinguish between solid solution oxygen and inclusion oxygen remains uncertain. Solid solution oxygen is of primary importance when considering age hardening. We are not certain that solid solution oxygen exists to an appreciable degree in steel. Oxygen in the form of inclusions may exert an indirect influence on age hardening by controlling grain size or similar effects.

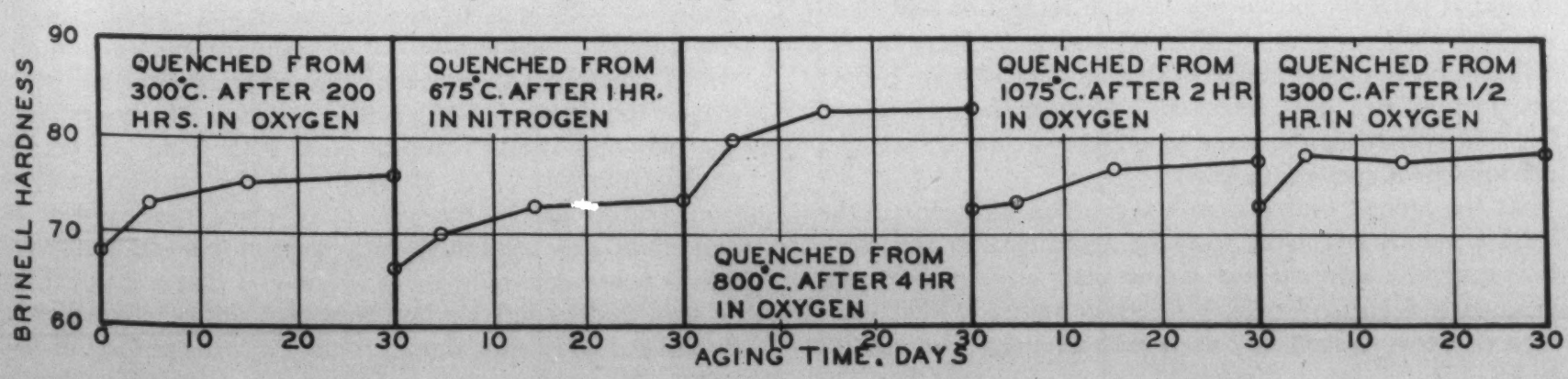
The present investigation like all previous investigations has been conducted without a means for determining solid solution oxygen. However, many total oxygen determinations were made and they contributed little information, except in case of the pure iron-oxygen alloys.

The selection of the property of age hardening, or aging as a means of studying the influence of oxygen in iron and steel, was made because of its scientific interest at the present time. The property of age hardening may be conveniently observed by simple methods of hardness testing and cold working. Many other methods may be employed but it is believed that hardness testing represents the most practical and simple test available. Properties other than age hardening are of equal importance with reference to oxygen but will not be considered at the present time.

Quench Aging

The age hardening of iron and steel, in the light of present knowledge, depends upon the formation of a supersaturated solution of a hard constituent in iron. This condition of supersaturation may be brought about by heating

Fig. 1.—Quench Aging of Iron Oxygen, Alloy No. I.


BRINELL HARDNESS
90
80
70
60
QUENCHED FROM 300°C. AFTER 200 HRS. IN OXYGEN
QUENCHED FROM 675°C. AFTER 1 HR. IN NITROGEN
QUENCHED FROM 800°C. AFTER 4 HR IN OXYGEN
QUENCHED FROM 1075°C. AFTER 2 HR IN OXYGEN
QUENCHED FROM 1300°C. AFTER 1/2 HR. IN OXYGEN
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AGING TIME, DAYS

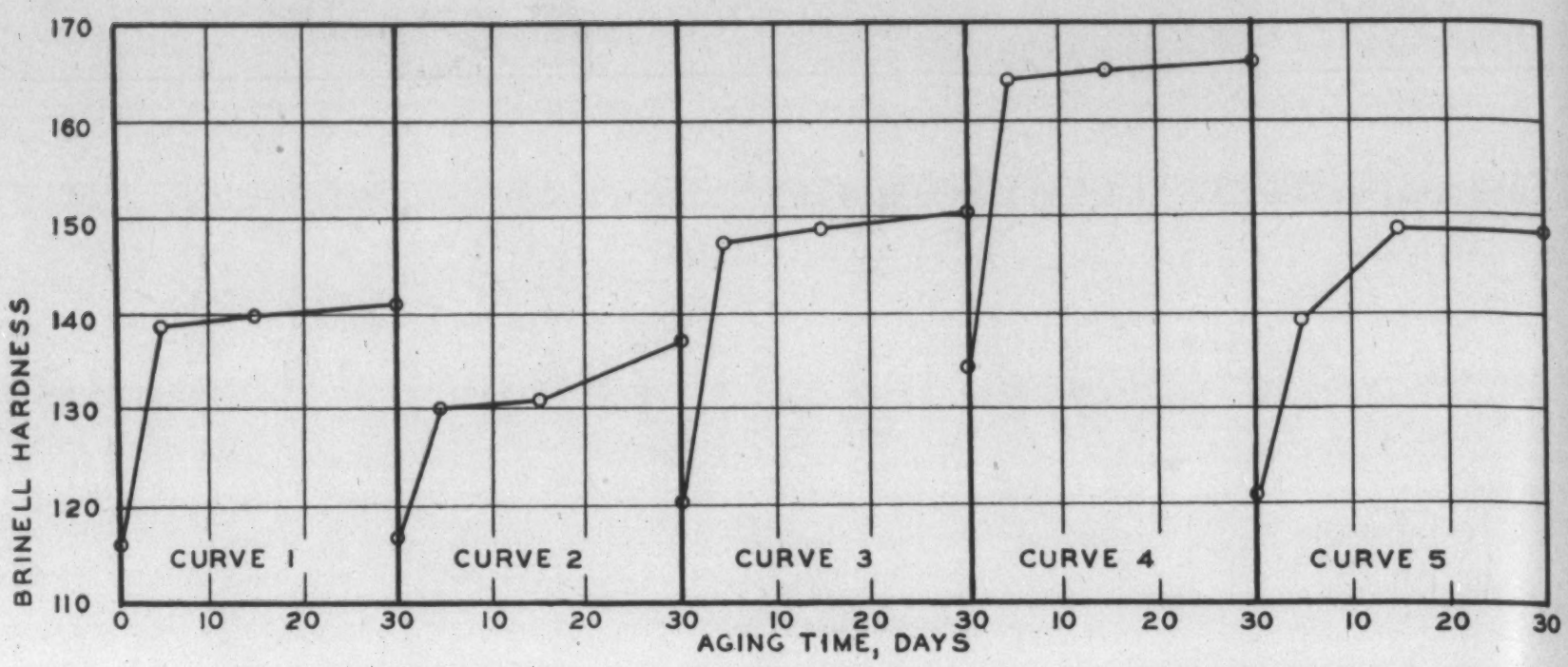


Fig. 2.—Strain Aging of Iron Oxygen, Alloy No. 1 (500 Kg. Brinell)...Curve 1—Annealed from 950 deg. C. after 1 hr. in nitrogen; Curve 2—Quenched from 300 deg. C. after 200 hrs. in oxygen; Curve 3—Quenched from 800 deg. C. after 4 hrs. in oxygen; Curve 4—Quenched from 1075 deg. C. after 2 hrs. in oxygen; Curve 5—Quenched from 1300 deg. C. after ½ hr. in oxygen.

iron to an elevated temperature in the region of maximum solubility and quenching. This type of age hardening is commonly called quench aging. The condition of supersaturation or instability may also be brought about by cold working. Iron saturated or unsaturated with an age-hardening constituent may by sufficient cold work be placed in an unstable condition. The age-hardening constituent in a suitably distorted space lattice acts as a supersaturated solution, otherwise no age hardening is observed. This type of aging is usually called strain aging.

A large amount of information has been presented in the literature regarding the aging of iron and steel. No attempt will be made to review all the literature in this field.

Herty and his associates[1] and Davenport and Bain[2] offer a selected list of references in addition to interesting experimental results. Honda, Gayler and others have in recent years developed various aging theories based on the knot theory as described by Merica.[3] In the absence of precipitation at room temperature, the knot theory may be applied to various alloys provided their properties conform with the theory. Burns[4] has stated that no supersaturation of oxygen, according to X-rays, is produced in alpha iron by quenching just below the A_1 critical point. Yensen[5] presents data indicating that oxygen may be a factor in the age hardening of iron. Tofaute[6] states that oxygen does not produce aging in steel.

Many other references could be cited to indicate that research workers have in some cases found evidence favoring oxygen and in other cases favorable evidence was lacking. In recent years the production of non-aging iron and steel[7] has received the attention of metallurgists. The principles utilized in the production of such steel depend upon proper deoxidation and heat treatment. Oxygen has, therefore, been considered as the important factor in the commercial production of non-aging steels.

At the present time carbon, oxygen and nitrogen are the chief elements associated with the aging of iron and steel. It is generally believed that carbon plays an important part in quench aging and oxygen in strain aging. Other common elements in steel may exert an influence. The general field of the aging of steel has been presented by Davenport and Bain[2]. The aging of steel with particular attention to oxygen is discussed by Daniloff, Mehl and Herty[8]. The solubility of oxygen in solid iron has been studied by Ziegler[9]. The general opinion has been that oxygen is soluble in iron at room temperature to at least 0.01 per cent and the solubility increases with rising temperature. The equilibrium diagrams are of the age hardening type. The present investigation is an attempt to throw additional light upon the influence of oxygen in the aging of iron and steel and to confirm the work of previous investigators.

MATERIALS AND METHODS

THE heat-treated specimens were approximately ½ in. thick and 1 in. square. The heat treatment usually lasted 1 hr. in the common type of electric furnace except in the case of pure iron samples treated in oxygen. Single specimens consisting of a core and rim of a billet were frequently used throughout the investigation. The results for the most part are based upon hardness readings obtained in the core. Freshly prepared surfaces were used before and after heat treatment to insure uniform results.

The analyses of all materials used in this investigation are presented in Table 1. Samples No. 1 and 2 were high-purity research-iron obtained from Dr. T. D. Yensen of The Westinghouse Electric & Mfg. Co. Electrolytic iron was melted and treated to remove various impurities in a vacuum furnace. The melting and refining operations were conducted several times. The iron bars were heated to 1400 deg. C. and hydrogen was passed through the furnace. Sample No. 3 was standard Armco iron obtained from Dr. A. Hayes of the American Rolling Mills Co., in the shape of 4-inch billets. Sample No. 4 was Norway wrought iron. Samples Nos. 5 to 9 inc., were obtained from Dr. C. H. Herty, Jr., of the Bethlehem Steel Co. Unfortunately, the amount of manganese, silicon or aluminum not combined with oxygen but alloyed with iron was not determined. It is essential that a material, to be stabilized by suitable heat treatment, must be completely deoxidized and hence should contain a small portion of the

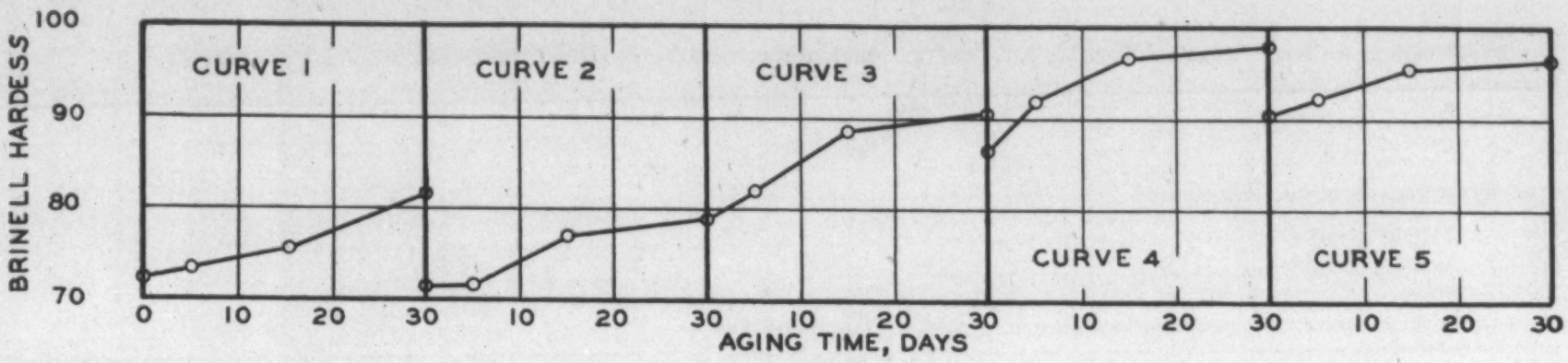


Fig. 3.—Quench Aging of Iron Oxygen, Alloy No. II. Curve 1—Quenched from 300 deg. C. after 200 hrs. in oxygen; Curve 2—Quenched from 657 deg. C. after 1 hr. in nitrogen; Curve 3—Quenched from 800 deg. C. after 4 hrs. in oxygen; Curve 4—Quenched from 1075 deg. C. after 4 hrs. in oxygen; Curve 5—Quenched from 1300 deg. C. after ½ hr. in oxygen.

deoxidizer alloyed with the iron. Sample No. 5 had no deoxidation. Sample No. 6 was deoxidized with manganese, Sample No. 7 with aluminum and Sample No. 8 with silicon. Sample No. 9 was prepared by deoxidation with manganese-silicon alloy in the furnace. Two pounds of aluminum per ton of steel and some ferro-silicon were added to the ladle. The steel was very clean.

The Rockwell hardness testing machine was used throughout the investigation and the readings were converted to Brinell hardness. At least four check Rockwell readings were taken and the instrument was read to the first decimal. The average of the four Rockwell readings was converted to Brinell hardness. Dr. J. L. Burns in a discussion of the paper by Daniloff, Mehl and Herty[8] has pointed out that the Rockwell scale is not satisfactory for age hardening studies when data are compared, hence the Brinell scale has been used for comparing data in this investigation. The accuracy of the Rockwell Brinell conversion is not 0.1 as reported in the tables.

The cold working was performed by making a Brinell impression and changes in hardness were observed by taking a Rockwell reading at the base of the Brinell. This method of cold working and hardness testing was originally suggested by Dr. A. Sauveur and proved to be very convenient and quite accurate. Several other methods using the Brinell impression were tried but the simplest method was finally adopted. This method of cold working has been described by Sauveur and Burns[10]. Usually a 500 kg. load was employed. The method is not adaptable to sheet steel. The cold working of steel in a tensile testing ma-

Table 1.—Steel Analysis

Sample No.	C	O	N	Mn	P	S	Si	Treatment
1	0.005	0.09	0.005	0.003	0.003	0.005	0.010	Refined electrolytic
2	0.001	0.10	0.005	....	....	....	....	Refined electrolytic
3	0.030	C* 0.06	0.005	....	....	....	....	Armco
		R† 0.02	....					
4	0.025	0.09	....	....	....	....	....	Wrought iron
5	0.04	C 0.04	....	0.08	0.012	0.032	0.008	No deoxidation
		R 0.02	....					
6	0.04	C 0.022	....	0.22	0.020	0.035	0.005	Mn deoxidized
		R 0.019	....					
7	0.03	C 0.03	....	0.03	0.006	0.006	0.001	Al deoxidized
		R 0.02	....					
8	0.03	C 0.019	....	0.06	0.007	0.035	0.094	Si deoxidized
		R 0.013	....					
9	0.19			0.46	0.010	0.028	0.050	Special deoxidized
10	....	....	....	....	....	....	....	No. 3—carburized 24 hrs. 1700° F. (926° C.)
11	....	....	....	....	....	....	....	No. 3—carburized 75 hrs. 1700° F. (926° C.)

* Core. † Rim.

Fig. 4.—Strain Aging of Iron Oxygen, Alloy No. II (500 Kg. Brinell). Curve 1—Quenched from 950 deg. C. after 1 hr. in nitrogen; Curve 2—Quenched from 300 deg. C. after 200 hrs. in oxygen; Curve 3—Quenched from 800 deg. C. after 4 hrs. in oxygen; Curve 4—Quenched from 1075 deg. C. after 2 hrs. in oxygen; Curve 5—Quenched from 1300 deg. C. after ½ hr. in oxygen.

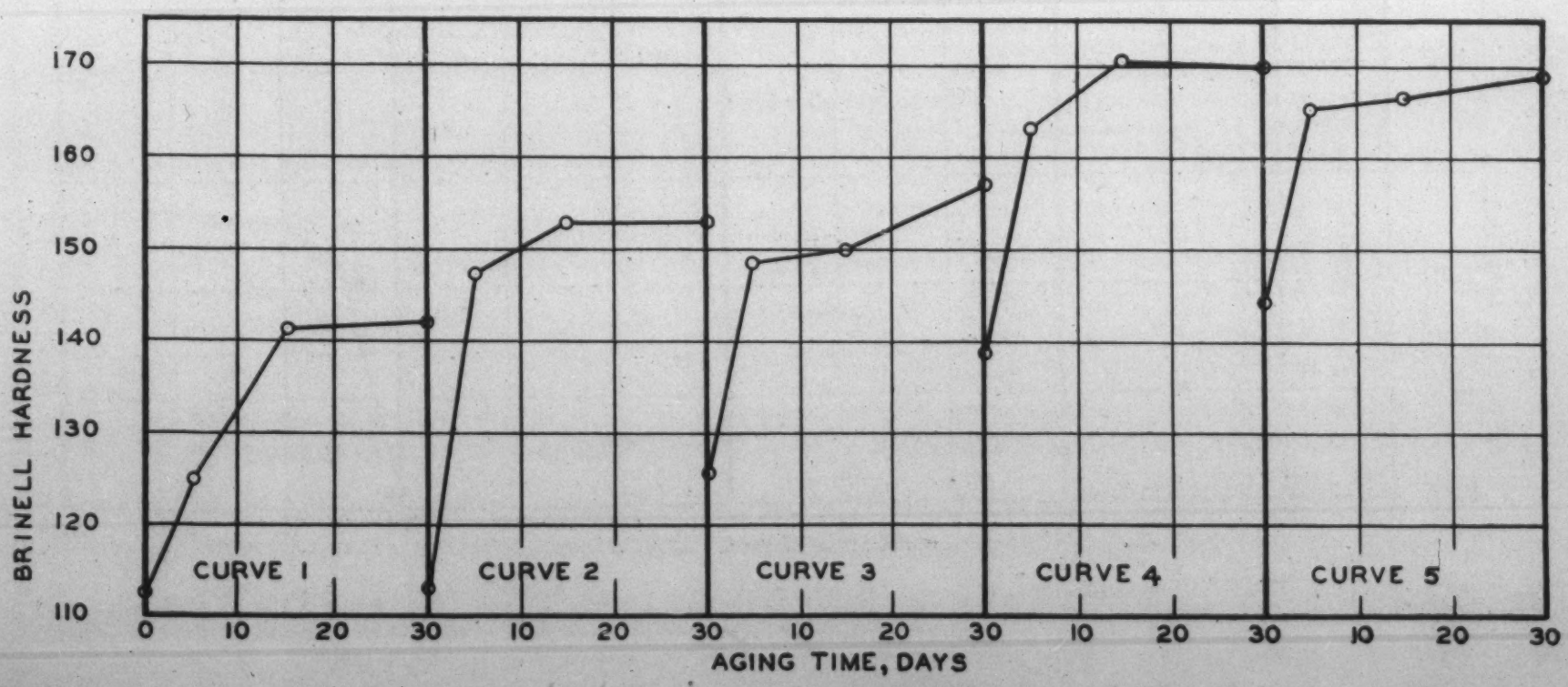


Table 2.—Aging of Iron-Oxygen Alloys No's. 1 and 2. Maximum Increase in Brinell Hardness after 30 days Aging.

Treatment	A* 1742° F. (950° C.)	Q† 572° F. (300° C.)	Q 1247° F. (675° C.)	Q 1472° F. (800° C.)	Q 1967° F. (1075° C.)	Q 2372° F. (1300° C.)
Hours in Oxygen at Q Temperature	0	200	0	4	2	½
			ALLOY NO. 1—NO COLD WORK			
Maximum increase in hardness	...	7.8	7.8	9.2	4.7	5.6
			ALLOY NO. 1—COLD WORKED, 500 KG. BRINELL			
Maximum increase in hardness	24.5	20.5	...	30.0	32.0	27.1
			ALLOY NO. 2—NO COLD WORK			
Maximum increase in hardness	...	9.2	8.0	11.9	11.2	5.9
			ALLOY NO. 2—COLD WORKED, 500 KG. BRINELL			
Maximum increase in hardness	29.3	40.0	...	32.2	31.0	24.5

* Annealed.
† Quenched in water after treatment in oxygen at temperature and time specified. The samples were not reheated after quenching.

chine followed after aging by stress strain-curves is an excellent method employed by Griffis, Kenyon and Burns[11]. The yield point and tensile strength rise after cold working and age hardening and the ductility decreases. The use of stress strain-curves requires much more time and expense as compared to the Sauveur method.

The pure irons, Samples Nos. 1 and 2, were treated in a vertical tube furnace with oxygen. The furnace was similar to Ziegler's[9], with the exception that a molybdenum winding in an atmosphere of hydrogen, and a platinum, platinum-rhodium thermocouple were used. The samples for oxygen treatment were ½ in. thick. At 572 deg. F. (300°C.) the samples were treated with oxygen for 200 hrs., and quenched. Longer periods of treatment were also used but are not reported as the results were similar. At 1472 deg. F. (800°C.) the samples were treated with oxygen for 4 hrs., 1967 deg. F. (1075°C.) for 2 hrs., and at 2372 deg. F. (1300°C.) for ½ hr., followed by quenching. It is believed that the time at each temperature was sufficient for equilibrium conditions[9].

The oxygen determinations were made with equipment constructed after Herty and co-workers[12]. The equipment consisted of a modified Ledebur method. Pure hydrogen was passed over chips of metal to be tested. The hydrogen reacted with the oxygen in the sample forming water which was collected and weighed. The results obtained by this method were fairly satisfactory for low carbon steel as compared to the vacuum fusion method and were accurate to 0.01. Vacuum fusion results frequently run lower in value than hydrogen reduction results[13]. In this investigation the results for vacuum fusion analysis of Armco iron were about the same as the results obtained by the modified Ledebur method of analysis.

RESULTS AND DISCUSSION

THE results of hardness readings are given in Tables II to VII and Figs. 1 to 12. They are expressed in the Brinell scale after conversion from the Rockwell scale.

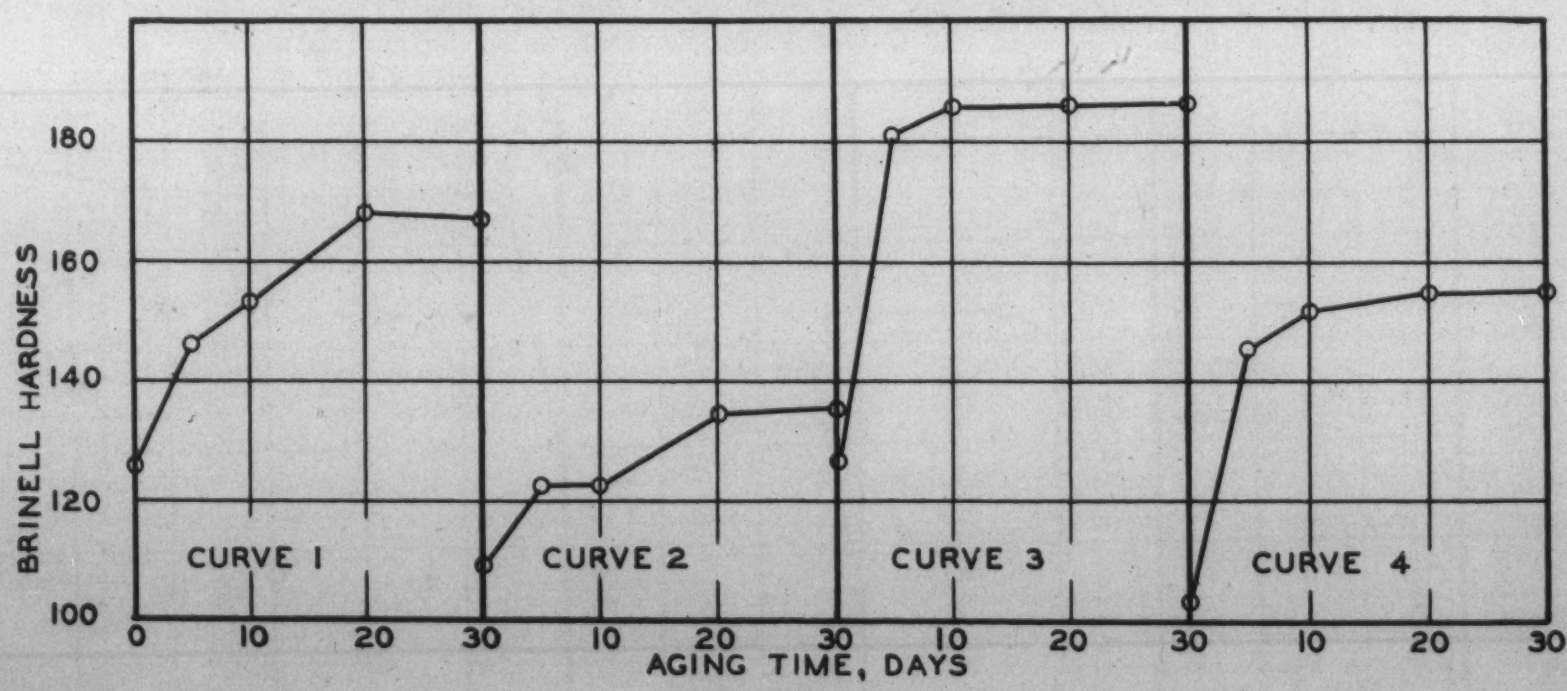
Quench Aging of Iron-Oxygen Alloys

The results obtained after heating alloys No. 1 and No. 2 in oxygen at temperatures ranging from 300 deg. C. to 1300 deg. C. and then quenching in water from the various temperatures are given in Table 2 and Figs. 1 and 3. It should be noted that the alloys hardened a small amount after quenching. If oxygen was the single cause of quench aging, the alloys would have exhibited marked hardness changes. The specimens quenched at 572 deg. F. (300° C.) age hardened to nearly the same degree as the remainder of the specimens. The original hardness after quenching and before aging was about the same for all alloys of the No. 1 series. This would indicate no aging in the quenching bath. For Series No. 2, aging occurred in the quenching bath, hence the actual hardness increase from aging would be greater than the table indicates.

The fact that aging has occurred cannot be satisfactorily explained on the basis of carbon. The carbon content in the specimens showing the most aging was very low, 0.001 per cent. The solid solubility of carbon at room temperature is at least 0.006 per cent[14].

Considering aging in the quenching bath in addition to the observed aging, specimens of Series No. 2 adapt themselves to the iron-oxygen equilibrium diagram. Specimens of Series No. 1 do not behave in the manner expected. The aging for the specimens quenched at 572 deg. F. (300°C.)

Fig. 5.—Quench Aging of Armco Iron, Alloy No. III. Curve 1—Quenched from 1060 deg. C.; Curve 2—Quenched from 850 deg. C.; Curve 3—Quenched from 950 deg. C. followed by quench from 650 deg. C.; Curve 4—Annealed from 950 deg. C. followed by quench from 650 deg. C.



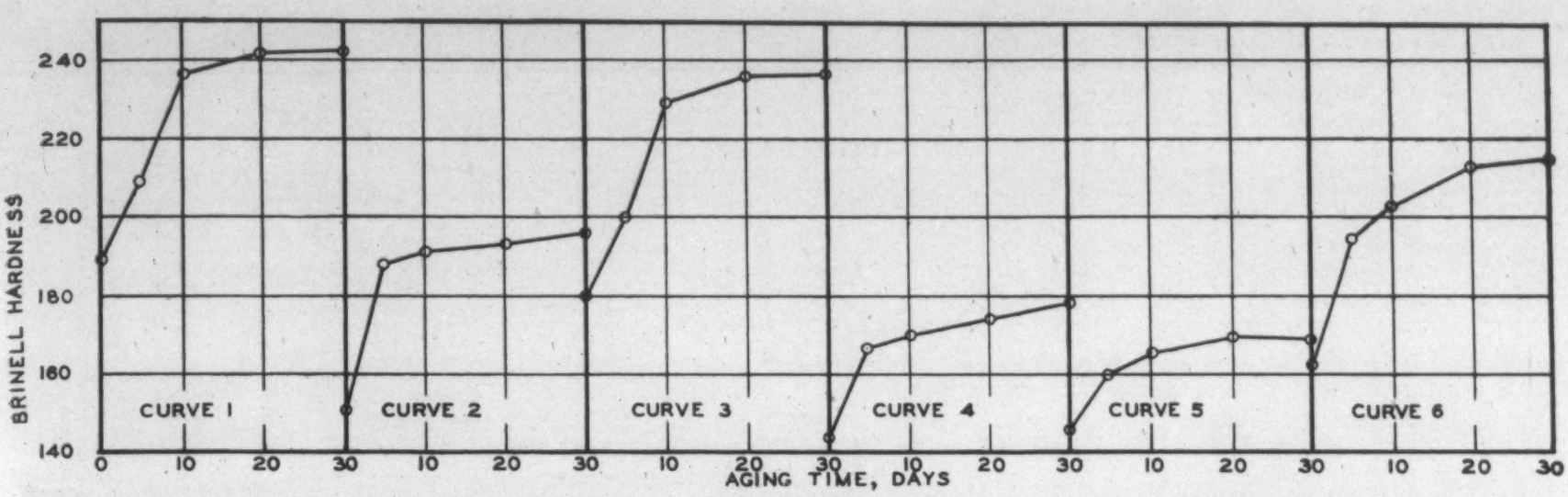


Fig. 6.—Strain Aging of Armco Iron, Alloy No. III (500 Kg. Brinell). Curve 1—Quenched from 1060 deg. C.; Curve 2—Quenched from 850 deg. C.; Curve 3—Quenched from 950 deg. C. followed by quench from 650 deg. C.; Curve 4—Annealed from 950 deg. C.; Curve 5—Quenched from 950 deg. C. followed by anneal from 650 deg. C.; Curve 6—Annealed from 950 deg. C. followed by quench from 650 deg. C.

is comparable to the specimens quenched at higher temperatures. The iron-oxygen equilibrium diagram is believed to be of the age-hardening type with maximum solubility at about 1832 deg. F. (1000°C.).

aging was obtained in all cases. It should be pointed out that quenching from 1742 deg. F. (950°C.) followed by annealing at 1202 deg. F. (650°C) and cold working at room temperature produced minimum age-hardening. This

Table 3.—Aging of Armco Iron, Alloy No. 3. Maximum Increase in Brinell Hardness After 30 days Aging

Treatment	Q* 1940° F. (1060° C.)	Q 1562° F. (850° C.)	Q 1742° F. (950° C.) Q 1202° F. (650° C.)	A† 1742° F. (950° C.)	Q 1742° F. (950° C.) A 1202° F. (650° C.)	A 1742° F. (950° C.) Q 1202° F. (650° C.)
			NO COLD WORK			
Maximum increase in hardness	42.0	26.4	59.5	...	...	51.6
			COLD WORKED 500 KG. BRINELL			
Maximum increase in hardness	53.0	45.8	57.0	34.0	23.5	52.0

* Quenched in water. † Annealed.

Strain Aging of Iron-Oxygen Alloys

Alloys Nos. 1 and 2, after heating in oxygen at temperatures ranging from 300 deg. C. to 1300 deg. C. and quenching in water, were cold worked by the Brinell method. No further treatment was applied to the samples before cold working, other than the quenching treatment from the various temperatures specified. The results obtained are in Table 2 and Figs. 2 and 4 and include data for alloys annealed from a temperature of 950 deg. C. All of the alloys exhibited marked strain aging. Oxygen is probably responsible for the strain-aging results. The hardness values should have increased more than the tabulated results in order to be comparable with all commercial low carbon steels. However, it is possible that some unknown factors may contribute to strain aging in certain steels.

The hardness after cold working and before aging is quite high in several specimens and this may suggest aging during the cold-working operation. The idea has been expressed[2] that an iron-oxygen compound is precipitated upon the slip planes of cold-worked steel. These data support the theory. No evidence has been presented to prove the precipitation of an iron-oxygen compound. It appears plausible, however, that this explanation is logical, at least until more conclusive evidence is available. Cold working produces a distorted lattice which acts as a supersaturated cold solution.

Quench and Strain Aging of Armco Iron

Various heat treatments were applied to Armco iron (Table 3 and Figs. 5 and 6) and marked quench and strain treatment will be referred to later in connection with other alloys.

The specimens quenched and cold worked did not age harden to the extent of the combined effect of quench aging and strain aging. This is explained upon the basis of aging during the cold-working operation. The initial hardness of the cold-worked specimens is greater, due to the aging during cold working and the usual hardening effect of distorted and broken grains. This observation indicates that hardness produced by cold work in steel is in part due to an aging process. The data obtained with iron-oxygen alloys might easily be applied to Armco iron, carbon playing the principal role in quench aging and oxygen in strain aging. The amount of strain aging in Armco iron compares favorably with the strain aging in annealed iron-oxygen alloys. The hardness results for Armco iron were taken from the core of a billet. Although the rim section of the billet was also examined, the results were not unlike those obtained in the core[15].

(To be concluded)

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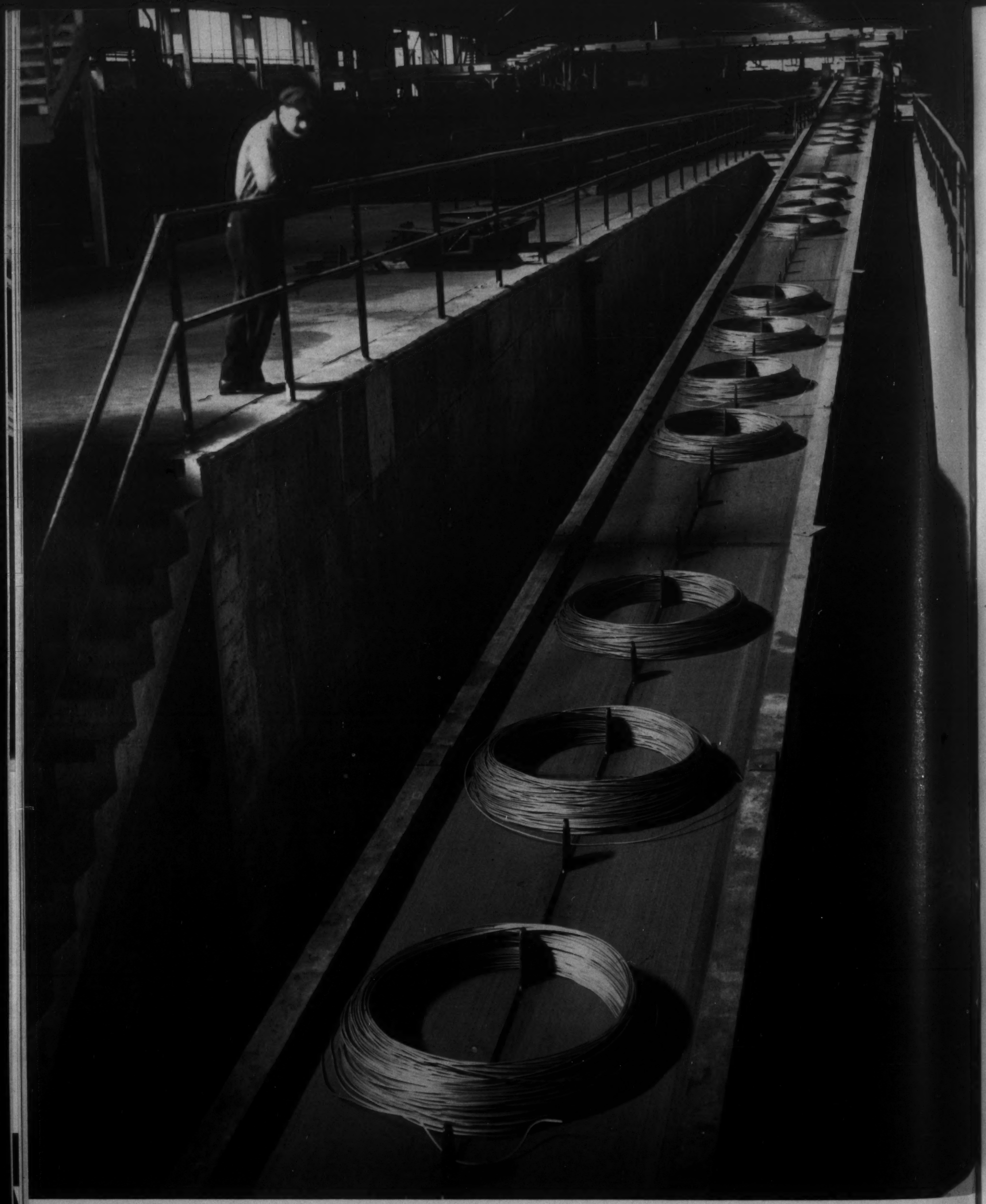


Courtesy: Bethlehem Steel Co.

Conveyor for Bundles of Coiled Rods in New Continuous Rod Mill at Maryland Plant

THE POSSIBILITIES OF

High Pressures in Powder Metallurgy

— A NEW DEVELOPMENT

by W. D. Jones

8 *Swan Lane,*
London E. C. 4.

AS IS NOW BECOMING WIDELY appreciated, the technique of powder metallurgy is developing a promising future. Not only have there been a number of gratifying developments during the last twelve months but there is in addition no doubt that the methods of powder metallurgy are receiving close attention in more quarters than is generally suspected. It may be of value, therefore, to bring to the notice of those interested in the subject a new development in technique in the realm of physics research which may have promise in future applications to powder methods.

Three Present-Day Methods

The details concerning the manufacture of articles by pressing and heating a metal powder have been comprehensively considered by the writer recently elsewhere[1]; all that is necessary to state here is summarized as follows: There are three chief methods of approach, (1) the hot press, (2) the cold press, (3) the combined hot and cold press.

In the first case, the metal powder is confined in a mould and in a loose uncompacted state is heated (either by heating the mould or by heating the powder only by the passage of current) to the sintering temperature and pressed. In the second method the powder is first of all pressed cold in the mould, ejected from the mould (and this usually necessitates some type of binder to give strength to the compact) and then separately heated to its sintering temperature. In the third case the powder is pressed both prior to heating and again at the sintering temperature either in the same or in a different mould.

These three methods have their relative advantages and disadvantages. For example, in the hot pressing method the powder is exposed to all the influences of the enveloping atmosphere, good or otherwise, and it may be necessary to devise methods for modifying such influences. In the cold pressing method there are advantages in the avoidance of being under the necessity of exposing a mould to pressures and oxidation at high temperatures. This is the method which is preeminently suitable for obtaining porous compacts but is less suitable for manufacture of non-porous articles although it is practised with success in the case of hard metal cutting tools made by sintering carbides. The combined cold or hot pressing process shares some of the advantages of both.

High Pressures, a New Development

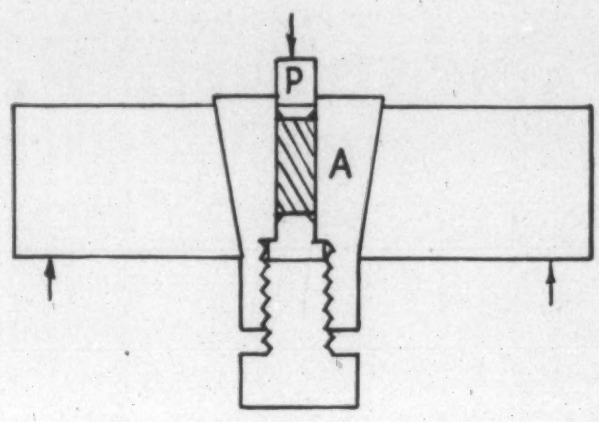
Having indicated very briefly the broad principle upon which the manufacture of sintered articles is based, consideration will now be given to the new development mentioned above and which is connected with the use of high pressures.

Pressures used in the compacting of metal powders are usually fairly low in the case of hot pressings primarily because of mould limitations. Figures of the order of 2000 to 20,000 lbs. per sq. in. are common. In the case of cold pressings, pressures are not always high, and 40,000 lbs. is quite usual in the case of manufacture of carbide alloys. In the working up of tungsten, pressures sometimes get considerably higher than this but there have always been serious practical limitations to very high pressures. Apart from die strength limitations, there is in particular the question of friction between the powder and the walls of its container, which, by preventing the attainment of hydrostatic conditions, causes a serious maldistribution of stress and may lead to subsequent fracture by lamination of the pressing. This obstacle has been considered by several workers on the subject and has led to a certain amount of patent literature where, for example,[2] hydrostatic pressure is obtained by enclosing the powder in rubber hose contained in a pressure vessel charged with high pressure water.

The Work of Bridgman

A new aspect on this matter has, however, been advanced by the work of Bridgman[3] and it is extremely surprising to find that this work appears to have passed unnoticed in powder metallurgy circles.

With his apparatus, which is admirably adapted for the pressing of powders under a normal type of press, Bridgman secures hydrostatic pressures of the order of 700,000 lbs. per sq. in. The principle is as follows: Only a brief description will be given here and it is recommended that the original paper be consulted. Referring to the illustration, which only shows the apparatus diagrammatical-



ly, the cylinder, A, in which the pressure is produced has a conical external surface like a stopper. Pressure is produced in this stopper by means of the piston, P. The thrust exerted on the stopper by the piston is taken up by the conical collar into which the stopper fits, and which exerts an external pressure on the stopper proportional to the total thrust neglecting friction. The magnitude of the external pressure on the stopper can be readily calculated and has attained a practical maximum, according to Bridgman, of about 425,000 lbs. per sq. in. with a collar of heat-treated "Solar" steel having a tensile strength of some 300,000 lbs. per sq. in. and an elongation of 8 per cent on 2 in.

The friction between collar and stopper is an important matter and is reduced to a low figure by the use of a lead film between the two to act as a lubricant. Ordinary lubricants such as oil and grease freeze solid at such high pressures. Even in the case of lead, it is necessary to have a copper film insulating it from the steel, otherwise lead is forced into the steel causing ruptures. The screw plug at the base of the mould is made from a heat-treated Cr-V steel and the plug at the bottom of the cylinder is made from glass hard "Teton" steel. No steel was found by Bridgman to withstand a compressive stress of 700,000 lbs. per sq. in. without continuous slow flow or immediate fracture and Carboloy proved to be the solution. Grade 905 was used for the plunger, and pressure was applied to it by means of a hydraulic press acting through a hardened "Teton" steel plate.

By this apparatus, of which only the barest details are given here, Bridgman has been able to make as many as 25 pressings at temperatures up to 200 deg. C. with one set up of the die set without replacements, although he states that, to work within the limits of safety, it is advisable to effect certain replacements after only a few pressings.

Practical Aspects

It may well be asked: "Has this work any real practical value to the powder metallurgist?" In reply to this the writer would point out that such high pressures have not yet found practical application, but would himself ask the question: "Are perhaps the technique and the materials of Bridgman the solution to die and wear problems when using much lower pressures?" This statement needs serious consideration. It might be said that the writer has already made useful use of the "stopper" principle in connection with the manufacture of hot pressings at high temperatures but quite low pressures.

In addition it is as well to make clear that the properties of compacts prepared by pressing metal powders under very high pressures are practically unknown. They may well have interesting and valuable physical properties and Bridgman's apparatus may be the means of attaining them. Trzebiatowski[4] for example reported Brinell hardnesses of over 180 in the case of copper pressings, combined with unusually high electrical conductivities. This development has already received consideration with respect to precious metals as far as contact points are concerned.[5]

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Comment by Prof. P. W. Bridgman of Harvard

I WAS MUCH INTERESTED in the galley proof of the article by W. D. Jones on "High Pressures in Powder Metallurgy." There are two or three comments which I might offer on the paper.

It has always seemed to me that there are industrial possibilities in the "stopper" method of strengthening dies, or other pressure vessels, against the action of internal pressure, and the application suggested in the paper is, therefore, of much interest. I think that there are other applications such as, for instance, to extruding various metals to wires or rods at lower temperatures, or under high pressures, or greater reduction of area, than can now be handled.

I have recently made a double application of the "stopper" principle with considerable increase of the strengthening which can thereby be produced in the pressure vessel. Attention should be called to a description given by Wesley P. Sykes, metallurgist, Cleveland Wire Works, General Electric Co., Cleveland, in the Twelfth Edward DeMille Campbell Memorial Lecture, at the Nineteenth Annual Convention of the American Society for Metals, held in Atlantic City, Oct. 18 to 22, 1937, of the alterations in the properties of iron powders subjected to exceedingly high pressures. It should be remarked, however, that the situation discussed by Mr. Sykes is complicated by the presence of an outside film of oxide on the grains.

Gold Filled Plate and Wire

IN THE OPTICAL INDUSTRY

by W. J. Wrighton and Tracy C. Jarrett

Metallurgists, American Optical Co., Southbridge, Mass.

THE MANUFACTURE OF GOLD-FILLED PLATE and wire consists of soldering solid gold sheets or tubes of the desired quality to an inferior base metal or alloy.

The earliest instance that is known of soldering gold to flat plate dates back to the nameless Memphite jewelers of the 12th dynasty (about 2400 B.C.). Throughout the ages, dating from 2400 B.C. up to the middle of the 18th century, the art of making gold and silver ornaments was carried on in Egypt, India, Greece, Italy, France and England.[1]

In the year 1742 Thomas Bolsover of Sheffield invented the soldering of solid silver plates to nickel silver with the aid of borax fluxes. This composite bar of silver plate, with a nickel silver base, was then rolled into sheets. From these sheets the well known Sheffield silver plate table ware originated.[2]

Until the year 1880 most of the gold filled plate was in sheet form made by soldering gold plate to base metals. This method left one or more of the edges of the base metal exposed. In the early 1880's Messrs. Thomas and James Frelley[3], Kaufmann[4], and Burdon[5] made seamless gold-filled wire.

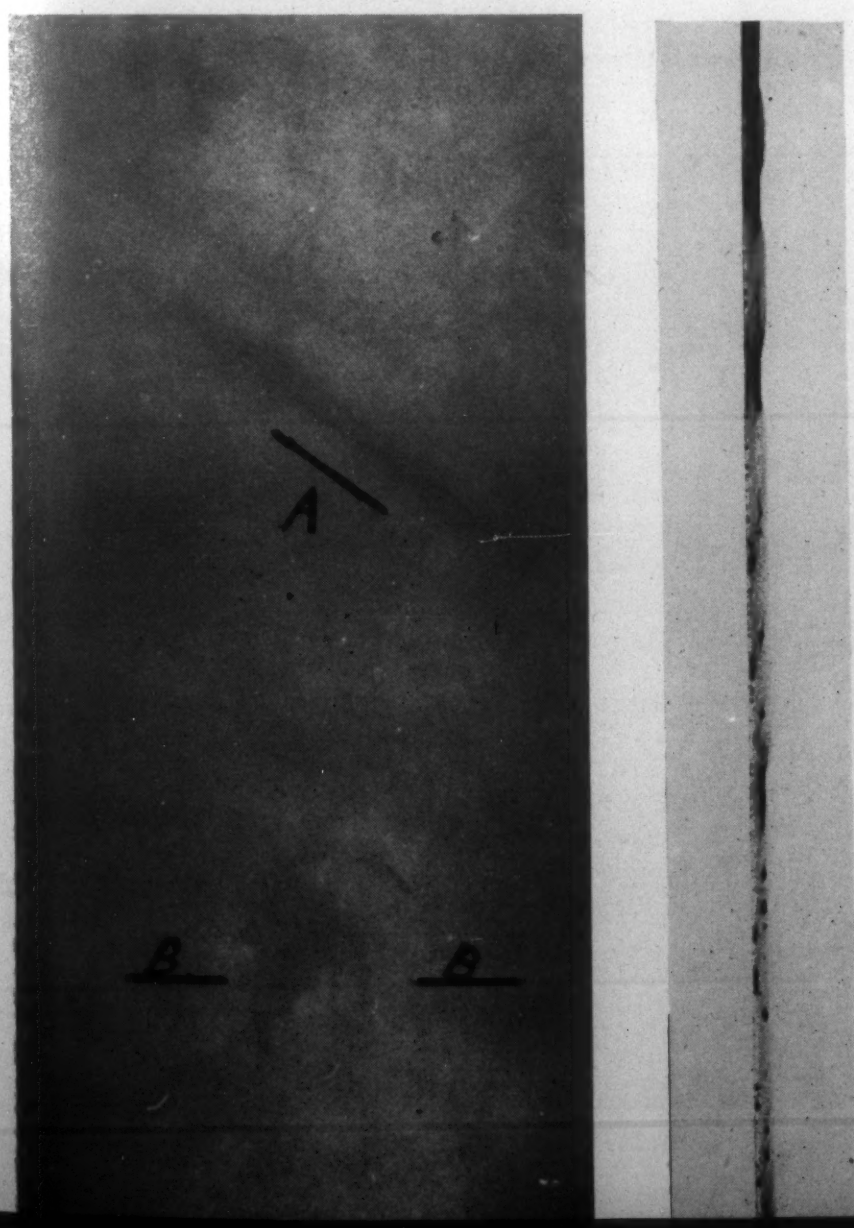
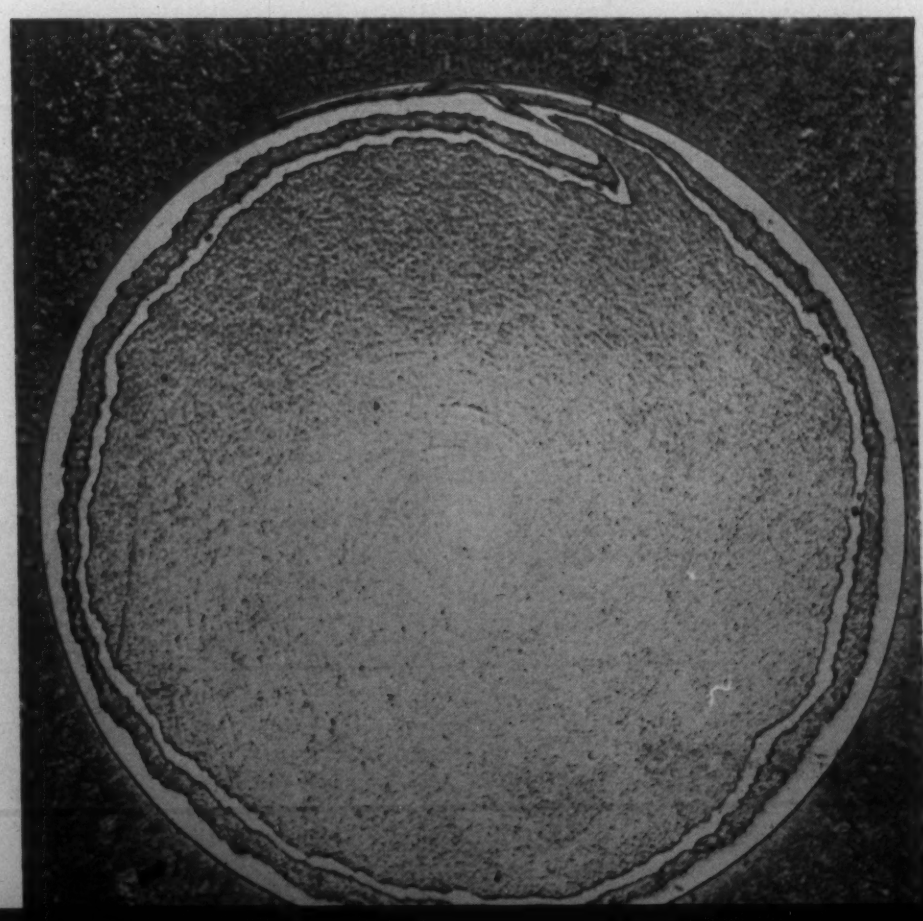
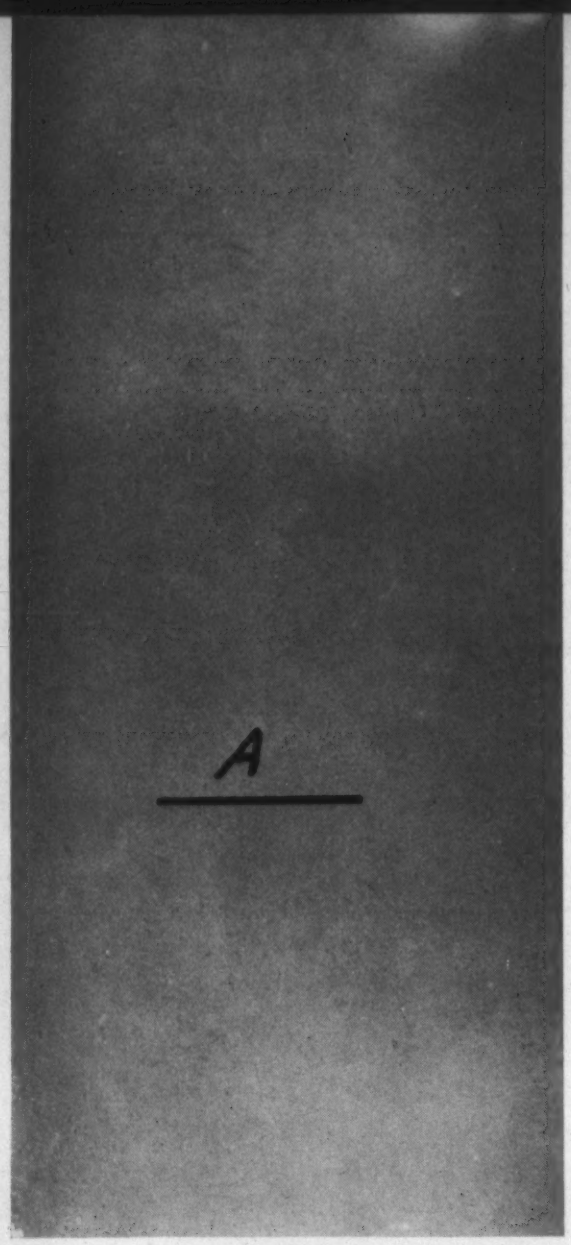


Fig. 1. Cross Section of Poorly Soldered Gold-Filled Wire. 100 X. Etched with ammonia persulphate. Radiograph of a Poorly Soldered Composite Cu-Au Plate. (Left) Cross Section Just Above and Parallel to Line A. 5X. Etched with ammonia persulphate. (Center)





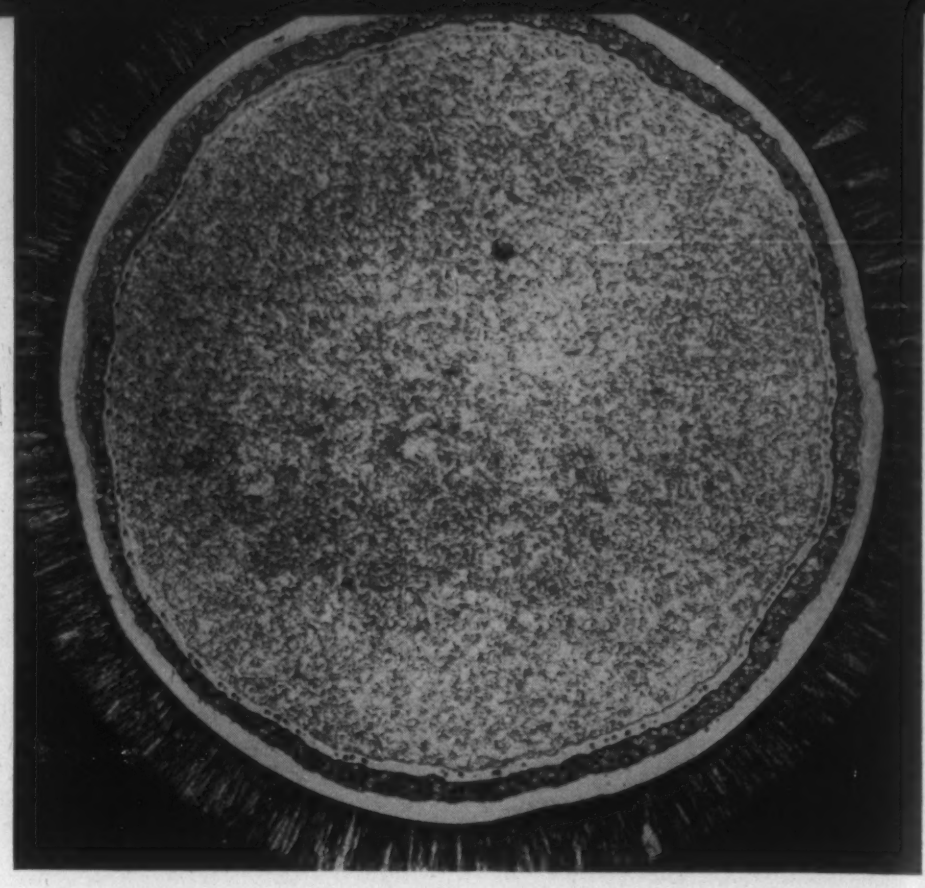


Fig. 2. Cross Section of a Properly Soldered Gold-Filled Wire. 100 X. Etched with ammonia persulphate. Radiograph of Properly Soldered Cu-Au Plate. (Left) Cross Section Taken Just Below and Parallel to Line A. 5X. Etched with ammonia persulphate. (Center)

This marks the beginning of our present gold-filled wire.

The necessary essentials of a base metal used in the manufacture of gold-filled wire cannot be found in one particular alloy. To clarify this, one spectacle mounting might require a core material of great resiliency, while another might require a stiffer material. In other cases it might be best to have a core material having either of the above properties and yet be non-corrosive. In the manufacture of spectacle mountings, it has been proven by experience that each one has its own specifications.

The gold that protects the core material also plays a very important part. First of all is the color of the finished article. The gold should be hard enough to stand abrasion and resist the facial acids. The metallurgist requires that the tensile strength, per cent elongation and reduction of area be such that it will fabricate. Also, the melting point

Fig. 3. Dies Used in the Making of a Gold Tube. The assembled tube, solder and core are being "pinched on" in the press.

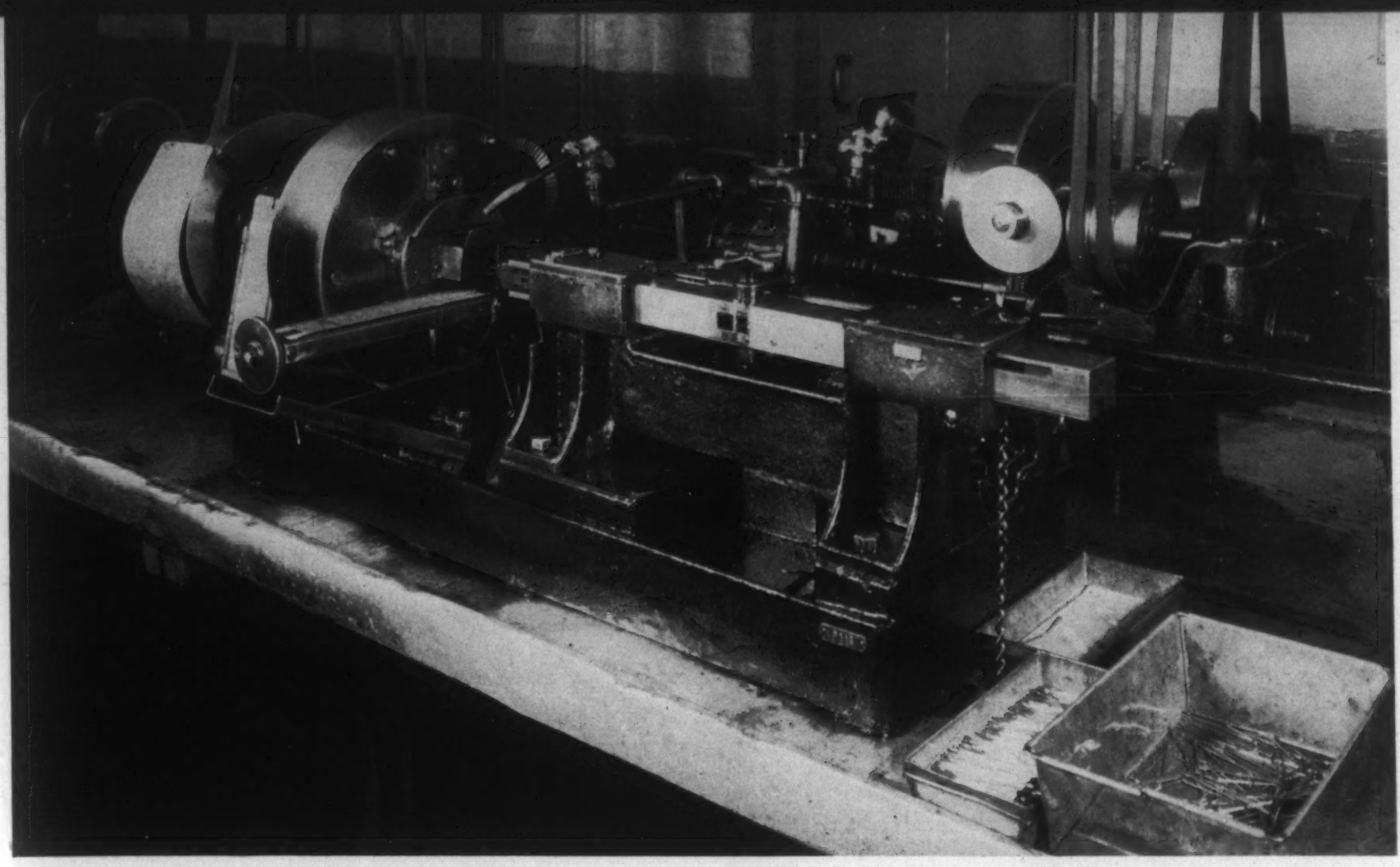


Fig. 4. Reducing Machine Used in Making Temple Butts for Spectacles.

of the gold must be high enough to withstand the annealing and soldering temperatures.

When these two parts—the gold tube and core—are soldered together, it is of the utmost importance that the fire assay meet the optical standards that have been set up.[6]

The gold alloys, consising of 10-12-14 karat, are melted in an induction furnace. It is essential that the melting of these alloys be kept under accurate control to produce sound ingots.

In the optical industry, the 10 and 14 karat golds generally are not used for gold-filled wire, but rather for the gold mountings. The 12 karat gold is used for the making of gold-filled wire and only the manufacture of such wire will be considered here.

The 12 karat gold ingot is pickled, washed, and rolled down to the size used for the composite plate. In rolling gold it is best to use heavy reductions before annealing. This is more necessary in the case of white golds, as cracking might occur after annealing if lighter reductions are used.

The composite plates, consisting of a gold plate and an inferior metal or alloy base plate, are soldered together, care being taken that the surfaces to be soldered are chemically clean. If the surfaces are not clean and the proper solder and soldering temperatures not used, a poorly soldered plate will be the result. (Fig. 1.) When these precautions are observed, good wire, as shown in Fig. 2, will be the result. The proper soldering technique was discussed in a previous article in METALS AND ALLOYS.[7]

The composite plate is rolled into a sheet and a disk blanked. From this disk, after several drawing operations, a tube with the gold on the outside is formed. The press used for these drawing operations and the partly drawn shells are shown in Fig. 3.

This tube, along with the silver solder and core, is thoroughly cleaned, fluxed and assembled by wrapping the solder around the core and placing it into the tube. After they are assembled, it is very essential that they are "pinched on," that is, the assembly is drawn through a die to produce an intimate contact between the surfaces to be soldered. (Fig. 3.) The gold-filled bar is then soldered in an electric furnace, after which it is rolled and drawn into finished wire. The relationship of the tube to the core

Fig. 5. Winding Cable for Spectacle Temples.

Fig. 6. Blanking Gold-Filled Bridges for Spectacles.

must be 1/10 of the gross weight. If a 12-karat gold were used in the making of this wire, then the assay should read 1/10-12 karat.

In many instances a flat gold-filled plate is needed instead of wire. This stock is made in a manner similar to the composite plate used for the tube, except that the bars are much heavier and often there is gold on both sides.

The gold-filled plate and wire are made into many different kinds and styles of spectacle mountings. Some of the wire is used for the manufacture of temples, bridges, and endpieces, while the flat gold-filled plate is used for blanked out bridges, endpieces, straps and such articles where it is impossible to use round wire.

In the making of a temple, wire of about 0.060 in. to 0.100 in. diameters is used and by reducing, which may consist of several operations, the butt end of the temple is made. (See Fig. 4.)

The cable part, the portion that rests on one's ears, is made of several windings. The inside windings are generally made from plain wire, while the outside winding is made of gold-filled wire. The size of the wire used for the different windings varies from 0.010 in. to 0.020 in. diameter. (See Fig. 5.) The finished cable and butt are then soldered together and after a number of different operations, the temple is ready for use.

It is possible to make bridges out of gold-filled wire or plate. When gold-filled wire is used, a reduction is necessary, such as used for temple butts, while in the case of flat gold-filled plate, the bridge is blanked out using a die. (See Fig. 6.) After the bridges are reduced or blanked out as the case may be, they are bent into the correct shape and engraved. The arms and straps are soldered onto the bridge and, after the polishing and finishing operations, the center is complete.

In the making of frames, about the same style of procedure as used in making bridges is employed. The different parts that go to make up the frame are reduced or blanked, and all soldered together.

This is a brief picture of the manufacture of spectacle mountings from the making of the gold-filled wire or plate to the finished article. Different styles and types of spectacle mountings are pictured in Fig. 7.

References

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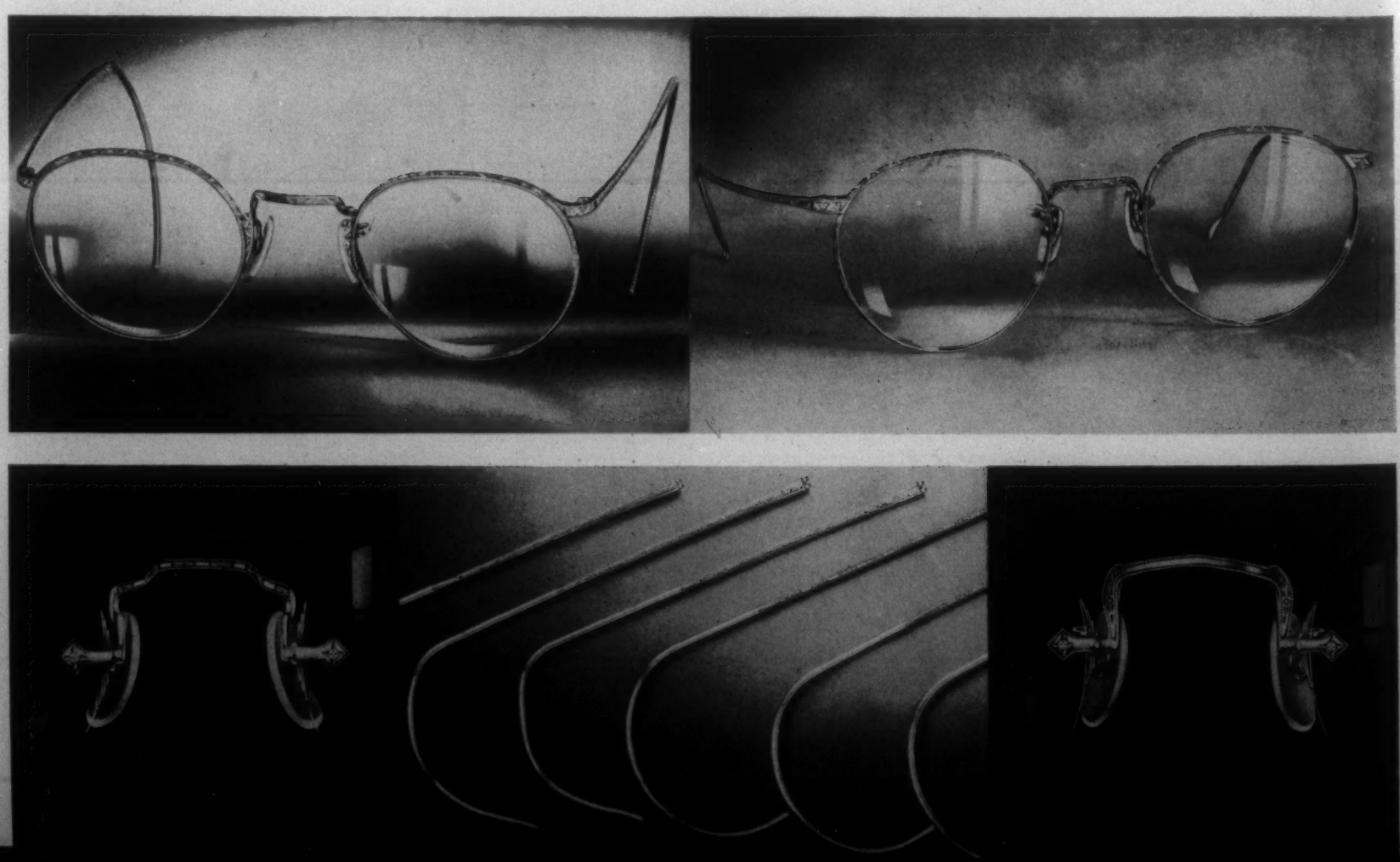
Fig. 7. Finished Spectacle Mountings Made from Gold-Filled Top-Frames.—Bottom (left to right). Center—Temples and Center.